ELEMENTS OF GEOGRAPHY

Physical and Cultural

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ELEMENTS OF GEOGRAPHY

Preface

The third edition of this book, like the two earlier ones, is designed to supply textual material covering the elements of geography in a form particularly suited to classroom discussion in beginning courses in college geography. The special merit of the treatment of the subject employed in this text is believed to lie in the choice of the material that has been included in it, in the structure of its organization, and in the manner of its presentation.

The selection of material for inclusion has been made with a single objective: to describe and depict the major elements of geography and to enable the student to acquire a background for interpreting the significance of their areal association. The material included is confined to the development of what may be considered a check list of the elements of natural earth and the elements of material culture. In this an attempt has been made to lay a solid foundation for studies in cultural geography by description and analysis of the habitat potentialities of the natural features of the earth and its conspicuous forms of human culture. The material is presented in a manner that the authors believe furnishes a basis not only for understanding on the part of the student but also for a full and rich classroom discussion of the subjects included.

The structure of the book's organization is considered by the authors an essential part of the presentation. It includes (*a*) two opening chapters which provide a degree of orientation in the field of geography, together with certain basic facts and geographical tools, and (*b*) two principal parts. The latter treat, respectively, of (i) the elements of natural earth and (ii) the elements of material culture

Part One of the book receives the most extended treatment, and it has been divided into five sections of several chapters each. This organization has the merit of enabling the student to distinguish clearly between the *elements* of weather and climate and the *types* of climate into which they are combined and of distinguishing earth *processes* from the classes of earth *features* produced by them. The emphasis has been placed deliberately upon the nature or form of the elements of geography and upon their world distribution rather than upon the processes of their origin. Not that the rational interpretation of features through the manner of their origin is neglected. It is employed constantly, but in part the discussion of process is segregated, and always it is made secondary in importance to the essential physical characteristics of the features produced. In this respect the treatment of landforms, for example, is to be distinguished sharply from that which is customary in physiography or physical geology. The point of view maintained throughout Part One is that the physical earth is the home of man and that consequently the resource potentialities of the physical elements are of paramount importance.

Part Two of the book alone deals with the features of material culture essential to geography. Omitting that part, the book functions as a basic text for a course in natural science. Just as Part One is an analytical treatment of natural features, so Part Two is a similar, but briefer, analysis of the *types of features* resulting from human beings occupying regions. This manner of treatment of the subject of material culture is new to American textbooks of geography.

The revision of the "Elements of Geography" has been suggested from three directions: the rapid advancement of knowledge in some of the

fields upon which it touches, the practical test of 12 years of classroom use, and the kindly criticism of professional colleagues. Section A of Part One, which treats of the elements of weather and climate, has required the most thorough revision. This has been made necessary by recent and extensive changes in physical climatology, particularly in those aspects of the subject dealing with the nature and behavior of air masses, fronts, the types and significance of storms, etc. In the revision of both Secs. A and B, the latter dealing with climatic types and their distribution, every effort has been made to abbreviate and simplify the numerous details in order that the essentials shall be emphasized and that the whole presentation may more readily be grasped by the beginning student. For each climatic realm there has been added a summary of its resource potentialities.

Sections C and D of Part One, which deal, respectively, with the origin of landforms and with the characteristics and classification of landforms themselves, have seemed to require less revision. The changes that were made have, it is believed, resulted in the clarification of obscure points, the avoidance of some controversial matters, and the omission of certain details on which there is recognized difference of scientific opinion beyond the concern of an introductory course. Similar changes have been made in Sec. E, which deals with earth resources, particularly in the chapters which are concerned with the nature and classification of soils and the distribution of the principal soil groups of the world.

In general structure Part Two resembles its counterpart in the second edition. As before, the discussion is concerned with the nature and classification of the significant elements of material culture manifest in the geographical scene. Their inherent qualities are analyzed, the bases of their classification are indicated, and the significant features of their world patterns are introduced. The purpose of this, however, is not to present a brief human geography of the world but to give added significance to the bases of classification upon which the facts of world geography may be brought into rational order in other courses which may follow this introduction to the field. The treatment of population and settlements shows the greatest number of changes. The present discussion is an attempt at a scheme of analysis and classification of cultural elements comparable with and parallel to that applied to the physical elements in Part One of the book. Admittedly, the development of theory and the body of knowledge adaptable to this procedure are less complete than for the physical elements, which are the special fields of several branches of science. It is not remarkable therefore that Part Two of the book is not equal in extent to Part One.

It may be asked why the authors have so restricted their discussion of the cultural elements of geography and why they have not dealt at some length with the social implications of the various elements of physical earth. In some geography books the description of each of the physical features is followed by a summary of the human activities supposedly related to that feature. For example, the study of the physical characteristics of mountains will be supplemented by a description of the activities "dependent on or centered about" mountains. Such a treatment bespeaks a belief that geographical science is primarily concerned with showing how and to what degree physical earth influences human affairs. To such a philosophy of their subject the present authors cannot subscribe.

It may be asked also why the authors have not enlarged upon numerous themes suggested by the discussions of the cultural elements. Why, for example, have they not considered the world patterns of wheat production or forest exploitation or of any other of the many topics which are a part of the body of systematic economic geography? It may only be stated that this was not their objective. Neither was it their purpose to explore the complex of areal associations that comprise the field of regional study in its full geographical sense. Rather, their purpose has been, as was noted above, to show that *the elements of geography, physical and cultural, are capable of analysis and classification* and to show something of the pattern of distribution of each

of these elements over the surface of the earth. Only after these functions have been performed does the student begin to distinguish the elements as such and to appreciate the significance of their areal associations. The details of these complex associations, whether treated from the systematic or the regional viewpoint, are, however, left to other authors and other courses of study.

Several grades of distinction in type have been employed in the part, section, chapter, and center headings of the book for the purpose of keeping before the student the nature of the structural outline within which he works. Also, the component *articles* of the chapters have been numbered serially through the book. It is believed that this feature will be of use in encouraging forward and backward reference by the student and in making easy the definition of class assignments by the instructor.

The authors have striven for readability as well as explicitness in the style of the text. They have undertaken also, sometimes at the expense of brevity, to place special emphasis upon certain phases of the discussion. The interrelated nature of the subjects treated and the structure of the presentation both facilitate emphasis. The same association of facts may be, and often is, approached from two or more directions in as many different connections. This has made emphasis possible by a judicious use of repetition or by restatement to suit the new occasion.

The style of presentation seeks to avoid being merely a compendium of facts. The elements of geography are ordered, and the student is led to distinguish, by comparison and contrast, similar but not identical elements. Since this text attempts to lay a good foundation for the understanding of the geographical forms, patterns, and associations of world regions, many statements of fact and association concerning the features of specific world regions or localities have been included. To study these statements most effectively the student should make frequent reference to an atlas. Instructors are urged to see to it that students have facilities for that kind of study.

The text illustrations have been drawn or selected with the special purpose of centering attention upon significant features under discussion and of making possible a reduction in the amount of descriptive text. To that end they are placed in as close proximity to the related text as possible, although, in order to save space, some illustrations are made to serve in more than one connection. Most of the illustrations have been considerably enlarged, which greatly increases their legibility. Numerous new illustrations have been added or substituted. It will be noted that there has been a radical change in the format of the plates. Formerly these illustrative materials were prepared in such a style that students were required to color them before the distributional facts which they were meant to portray became obvious. They were in the form of a laboratory exercise. Many instructors teaching nonlaboratory courses in geography could not find time to have the plates colored, with the result that in their present form they were dubiously useful. With this in mind four of the most used plates now appear in color, while the others are in contrasting shadings. Two of the colored plates appear as end papers as well as in folded form in the pocket at the back. Sets of uncolored and unshaded plates may be obtained from the publisher by those who still wish, for the purpose of laboratory exercises, to use the plates in their previous form. Relatively few rainfall and temperature data have been presented in graphic form in the text, since it is believed that the student profits much more by the construction of these graphs for himself. A plate containing a number of coordinate paper blocks provides facilities for doing this. In addition to the classified climatic data provided for the several types of climate within the text proper, data for other stations are available in Appendix A.

Through teaching experience it has been found that in many introductory courses there is scant time for the development of the subject matter relating to forms of map projection, although the instructor might like to present it. However, some teachers and students are not so restricted. For their use a brief sketch of the subject of map projections is included in

Appendix B. Some of the more common forms of projection are illustrated there, the manner of their construction is briefly stated, they are compared, and their appropriate uses are suggested.

Appendix C deals with the American systems of land survey.

Appendix D presents a selected list of United States Topographic Quadrangles grouped according to the classes of land-surface features they illustrate. It is hoped that this list will aid in the preparation of valuable exercises to supplement the text in courses that permit of laboratory work.

Appendix E is intended as an aid to the student in acquiring the sense of time and order in earth history without which he cannot grasp the full meaning of the surface features of the land.

Reference lists are appended to those chapters, sections, or parts of the book which treat of distinct fields without conspicuous overlap in source material. These have been revised to include significant publications of recent date. The lists are not intended to be merely the references consulted by the authors, although many of those are included, and their aid is acknowledged with gratitude. The purpose of these lists is to suggest some of the more recent and authoritative general works in each field. In these the instructor or the gifted student may find supplementary reading with which to broaden his understanding of the subjects considered.

The indebtedness of the authors for valuable suggestions, illustrations, and other kinds of aid extends in many directions and to numerous individuals. This cordial cooperation is much appreciated.

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Elements of Geography

Physical and Cultural

CHAPTER 1: *The Field of Geography: Its Content, Method, and Point of View*

1. Content of Geography. Geography is the science of the earth's surface. It consists of a systematic description and interpretation of the distribution patterns and the regional associations of things on the face of the earth. (As the geographer conceives the surface of the earth, it is in the nature of a thin shell that extends slightly above and below the surface proper.) It is within this thin zone of contact between the atmosphere above and the solid and liquid sphere below that life in its various forms exists. Here organic and inorganic forms are closely intermingled and intimately interrelated, and from their combined patterns of distribution there emerges an earth's surface of variegated form and color.

Interrelated earth features exist together in different regions in contrasting associations and patterns. Geography seeks to discover what these regional associations and patterns of earth features are, or in other words, what the various parts of the world are like, how they resemble, or differ from, one another, and why. The principal concern of geography, then, is with the earth's regions. Its point of view is chorologic. As history has reference to time and treats of facts in terms of their chronological sequence, geography orders its materials with respect to their spatial or areal arrangements and distributions.

The Geographic Features of the Earth's Surface

2. Physical and Cultural Features. It may be asked, "Specifically what is it about the earth's surface and its regions that the geographer studies?" It is probably true that regional differences may be the result of an almost unlimited number of interrelated features and facts. Theoretically, therefore, the facts of geography are almost limitless. Actually, however, a great majority of geographers focus their attention upon two classes of interrelated earth features:

(*a*) those which are provided by nature (among them, climate, surface configuration, soils, economic minerals, surface and underground water, and native plant and animal life) and (*b*) those which man has added through living on the earth and using its resources (population, houses, settlements, communications, farms, factories, mines, etc.). These two groups are designated as the *physical*, or *natural*, features and the *cultural* features. The latter are composed chiefly of the *material observable features* resulting from man's productive activities in earning his livelihood and from his creation of shelter buildings and means of communication. These are the cultural features of primary importance. Some would add to these, other less tangible aspects of human development, cultural and political, which are closely associated with the material features. In addition to the distinctly man-made, or cultural, features, there are others of natural origin which have been modified by human beings. Cultivated soils, for instance, are not exclusively either natural or cultural, and the same is true of much of the earth's vegetation cover. *These material features, of both natural and human origin, are the principal elements of geography*, and it is with them that the present volume is concerned.

It is not, to be sure, in the numerous *individual* features of the earth or its regions that the geographer is primarily interested. A catalogue of individual plants is not botany, nor is the listing of things to be seen within any portion of the earth's surface geography. Scientific study requires grouping and classifying and the tracing of origins and connections. When it is noted, for instance, in a study of the geography of an area, that there are *repeating patterns* of population distribution, drainage lines, fields, or any of the other very numerous features, and when these repetitions are discovered to have definite causal relation to other features (past or present) with which they are areally associated, there is then the beginning of scientific geography. The classifying of the regional features according to origin, function, or some other basis into groups and the revealing of the bonds of connection between them are the geographer's task. Characteristic and repeated *patterns* and *associations* of features, then, rather than individual features are most useful in understanding the geography of the earth's surface.

The diagrammatic outline on page 3 may help to clarify the preceding analysis and explain in part the order of treatment in the chapters to follow.

3. *Description and Explanation.* As in many other sciences, so in geography: careful, systematic, direct observation and description are preliminary to and necessary for any classification and explanation that may follow. The geographer, in his study of any region of the earth or of any single geographic element, first of all systematically observes and then records, usually on a map, the results of his observations. Unlike most scientists, a geographer needs to describe and understand things that are much larger than his range of vision. The microscope is of little or no use to a geographer. His problem is to bring the patterns of widespread and far-flung features, distributed over countries, continents, or even the world, within his range of study. He must see them in their relations to each other, and to do this he is obliged to reduce them to observable size on maps. Maps, then, with their great variety of symbols, become the technical language of geographers. No other science, social or natural, makes use of them to anything like the same degree.

The second step, following observation and description, is the search for explanations as to why the patterns of distribution are as they are. No limit is placed upon *kind* of explanation. The physical earth, or natural environment, is only one of a great variety of things affecting man's use of a region, and it holds no preferred position among the several influences. There is, to be sure, no attempt to minimize the importance of the natural equipment of a region in its effects upon land use. But historical antecedents, customs and habits, laws, tariffs, and multitudes of other social forces likewise influence the character of land use, and they are as "geographic," as far as explanation of the cultural scene is concerned, as is a coal field, a mountain barrier, a soil type, or any other feature of the natural earth.

4. Geography Not Exclusively either a Natural or a Social Science. Since the earth's surface, which is the focus of a geographer's study, is composed of natural as well as of cultural features, it is obvious that geography cannot be exclusively either a natural or a social science but belongs to both. It is inherently dual in character. If one studies the earth or any part of it, one is likely to deal with both (*a*) its natural equipment and (*b*) the human imprint upon it, and such is the nature of most geographic studies.

Physical Geography. It is entirely feasible, however, for one to study the patterns and associations of the natural features while for the moment ignoring the cultural, and there is a group of geographers that chooses to cultivate this more restricted physical aspect of regions. Characteristically, physical geography has a humanized perspective, for it is usually an analysis of the whole natural equipment of a region, or some element of it, in terms of its resource potentialities for human use. Such a study provides a solid foundation not only for cultural, or human, geography but for all the other social sciences as well. The associated original natural features of a region, unmodified by human beings, are designated as the *fundament.*

Cultural, or Human, Geography. On the other hand, one may, if one chooses, focus one's principal attention upon the man-made features of a region, while minimizing, although certainly not ignoring, the physical aspects. The thing to be understood is still the earth's surface, but it is the surface as modified by the human beings living in and using the region. Human geography thus becomes a study of the "culture surface" and as such is a social science, claiming a place along with history, economics, anthropology, and others in an investigation of the human record. However, geography is concerned not primarily with human relationships, but rather with the features that man has inscribed upon the earth's surface, including population. The data of cultural geography are chiefly forms of land utilization. These features

GEOGRAPHY

The Science of the Earth's Surface and Its Regions

The distinctive geographic character of any portion of the earth's surface is largely determined by the areally associated and interrelated natural and cultural features, in conjunction with the fact of

Relative Location

Physical or Natural Features
1. Climate
   a. Temperature
      (1) Of the warmest and coldest months
      (2) Length of the frost-free season
   b. Precipitation
      (1) Total annual amount
      (2) Distribution throughout the year
      (3) Reliability
   c. Type of climate
2. Surface configuration and drainage
   a. Earth materials—nature of underlying rock
   b. Principal landform groups—relief and slope characteristics
      (1) Plains
      (2) Plateaus
      (3) Hill country
      (4) Mountains
   c. Surface features of a smaller size
   d. Drainage
3. Earth resources
   a. Water resources of the land
   b. Native vegetation and animal life
      (1) Forest
      (2) Grass
      (3) Shrub
   c. Soils
      (1) Physical and chemical properties
      (2) Character of profile
      (3) The great soil groups
   d. Economic minerals

II. *Cultural (Man-made) Features*
1. Population
   a. Numbers and density
   b. Distribution patterns
2. Houses and settlements
   a. House types
   b. Settlements
      (1) Dispersed
      (2) Agglomerated
3. Features associated with production
   a. Agriculture
      (1) Size and layout of farm and fields
      (2) Crop or animal specialization
      (3) Distribution pattern of agricultural land
      (4) Types of agriculture and their world distribution
   b. Manufacturing
      (1) The industrial plant
      (2) Raw materials, power resources, and finished products
      (3) Manufactural regions of the world
   c. Extractive industries
      (1) Logging
      (2) Fishing
      (3) Hunting and trapping
      (4) Mining
4. Features associated with transportation
   a. Routes of travel—density and patterns
   b. The carriers
   c. The things transported—foreign and domestic trade

of human origin within regions rest upon, and grow out of, the earth's physical surface. But in no sense is the physical surface to be thought of as the sole cause of the character and distribution of material culture. It is the human group, with its particular heritage of racial endowments, customs, habits, and training, that creates the features of land utilization, and it is the human element also that largely determines their character and distribution. Physical conditions set up only certain very flexible limits to land use.

5. *Regional and Systematic Geography.* The features that exist together on the earth's surface may be studied in a number of ways. Probably the most logical way to study them is in their natural groupings, *i.e.*, by *regions*. The face of the earth may be thought of as composed of a mosaic of regions differing from one another in their natural and man-made (cultural) features. In other words, each region has individuality or distinctiveness by reason of the kinds and arrangements of the features that occupy its surface. To delimit these regions, to describe and explain their distinctive characteristics, and to understand the bonds of connection between them—this, according to many geographers, is the core of their science.

It is possible, however, to study geographic features in their *systematic* rather than their regional groupings. By this method landforms, climates, human settlements, manufacturing types, crops, and the like may be made the subject of observation, description, classification, and explanation. In the evolution of geographic science many of the systematic groupings which it formerly included and cultivated have been partly or even largely taken over by more recently developed sciences. Thus to the mother science, geography, was born a group of offspring—geology, botany, zoology, meteorology, climatology—and each attained independence by taking over a part of the parental estate and successfully cultivating it. Nevertheless many qualified geographers still work successfully in the several branches of systematic geography and their bordering sciences.

6. The Present Book: Title, Content, and Organization. If the position is taken that geography is primarily concerned with a study of the earth's surface, it remains to be pointed out what particular contribution to that study this book is intended to make. It is in the nature of an introduction to geography through a systematic study of the individual elements or features that together comprise the face of the earth. The title of the book suggests this content. In no sense is it intended to be a general summary of geographic knowledge. On the contrary, the purpose is to acquaint the beginning student with the fundamentals of geography and to offer suggestions as to how they may be used in the understanding of the earth's surface. It is more in the nature of an outline of geography, the content of which provides organization and factual material on the physical and cultural earth.

Various methods have been employed by different authors in making this introductory approach to geography. One very common way has been through the channel of formal physiography, in which emphasis usually is placed upon a study of such physical *processes* and *agents* as rivers, glaciers, weathering, diastrophism, and storms. Less attention is given to physical *features*, their regional associations, potentialities for human use, and world distribution. Some other books minimize the treatment of physical processes and emphasize instead the characteristic human developments within the several great physical realms of the world. Still others are condensed compendiums of information summarizing the whole field of geographic knowledge. As stated in the preceding paragraph, this book makes the approach to the study of earth regions through a treatment of their observable material features, these being the principal elements of geography.

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CHAPTER 2: *The Earth: Its Shape, Planetary Relations, and Representation on Maps*

7. Many familiar conditions, both in the realm of nature and in everyday life, have their origins in the shape and size of the earth and its relation to other heavenly bodies, especially the sun. Common ideas of distance, area, direction, time, and weight depend upon these conditions of earth size and planetary relation. Such phenomena as day and night, the seasons, the tides of the ocean, and indeed the very existence of the oceans and the atmosphere depend upon them also. The external relations of the earth require study, therefore, because of their fundamental importance to an understanding of the nature of earth environment and of the many complex ways in which natural features are associated with those that have been created by man.

8. The Shape of the Earth. So slight are the earth's departures from true sphericity that the greatest of them amounts to less than one-third of 1 per cent of its 4,000-mile radius. A slight flattening at each earth pole causes the radius from the earth center to the pole to be about 13.5 miles shorter than the distance from the center to any point on the equator. That is the earth's greatest departure from true sphericity. Great ocean deeps (6 miles or more below sea level) and high mountain peaks (5.5 miles above sea level) exist, but the height of the highest mountain above the lowest point on the ocean floor is not more than the amount of the polar flattening. If the 25,000-mile circumference of the earth be represented by a true chalk circle, the largest that can be drawn on an ordinary blackboard, the chalk line will have more than enough thickness to include all the earth's departures from true sphericity, if they could be represented properly at that scale.

9. Earth Features and the Earth Interior. The nature and relative smallness of the departures of the earth's surface from truly spherical form have a meaning of wider interest than their mere size. It seems surprising that some of the great mountains of the earth are not higher and that the great ocean depths are not deeper than they are. Forces of crustal distortion are at work now, and have worked since the origin of the earth, at bending, breaking, and heaving the crust by unbelievably slow motion which appears capable of producing irregularities much greater than those which exist. That they are not greater seems due to a natural limit upon the size to which they may grow, a limit set by the plasticity of the earth and the inability of the interior to support the weight of huge projections upon its exterior. The earth ball appears perfectly rigid, and probably it has in fact about the rigidity of steel. Yet even this great strength seems incapable of supporting features of a greater order of height than that of the existing continental masses. If the earth be thought of as composed of a mosaic of segments or blocks, it is obvious that those which include the continents are slightly taller, measured from the center of the earth, than are those which include the ocean basins. It is believed that the higher segments are composed of rocks sufficiently lighter than the average so that they are nearly in balance with the lower but heavier segments. This state of balance is constantly disturbed by various of the earth processes, such as the removal of earth from the continents by streams

and its deposition in the oceans, and is constantly regained by the slow movement of plastic material beneath the earth's crust. The polar flattening of the earth also suggests a plastic earth interior, since that form of distortion of shape would be produced in a plastic sphere by the centrifugal force caused by slow rotation. The idea that the earth is plastic will be useful later in connection with studies of the molding of the surface forms of the land.

10. Land, Water, and Air. The home of man is upon the 197 million square miles of the exterior of the earth, but the major parts of which it is composed are very unlike in their degrees of human utility. The solid mass of the earth (the lithosphere) is covered in part by water (the hydrosphere), and both are surrounded by a gaseous envelope (the atmosphere). Each of these spheres touches upon the life of man in many ways, and their many different features or phases combine and recombine in hundreds of ways to make the sets of natural features that characterize different regions of the world. Some of the combinations form regions that are eminently suited to the habitation of man and to intensive use by modern human society; others form regions that are very unsuited. In the latter group are the depressed segments of the earth crust which are filled by the oceans and the great seas. These together occupy about 71 per cent of the surface of the sphere, leaving the smaller part, about 29 per cent, as the exposed continental surfaces. Only the latter are in any degree suited to permanent human abode.

The total area of the land and ice-covered surface of the continents is, therefore, only about 57 million square miles, equal to about nineteen times the area of the United States. Upon this rather restricted surface the entire human population of the earth resides and endeavors to secure a living. However, there are large parts of the land which, for one reason or another, are ill suited to intensive human occupation or use. The primary purpose of this book is to direct attention to the many different phases of the major elements, land, water, and air, which are combined in the natural equipment of areas; to emphasize those features and conditions which are inherent in the earth but which go together in so many different ways and give to various regions of the earth differences of physical appearance and of human utility.

Earth Motions

11. Earth Rotation and Its Consequences. The earth is held in space by the combined gravitational attraction of other heavenly bodies and has motions that are controlled by them. The two principal earth motions are *rotation* and *revolution*. The earth rotates upon an imaginary axis which, owing to the polar flattening, is its shortest diameter. The ends of the axis of rotation are at the earth poles. The time required for the earth to rotate once upon its axis is 24 hr. During that time each place on the sphere is turned alternately toward and away from the sun, has experienced a period of light and a period of darkness, and has been swept over twice by the circle of illumination, once at dawn and again at twilight. The direction of earth rotation is toward the east. This fact has broad significance. Not only does it determine the direction in which the sun, moon, and stars appear to rise and set, but it is related to other earth phenomena of far-reaching consequence, such as the prevailing directions of winds and ocean currents, which will be studied later.

12. Earth Revolution. The rotating earth revolves in a slightly elliptical orbit about the sun, from which it keeps an average distance of about 93 million miles. The time required for the earth to pass once completely around its orbit fixes the length of the year. During the time of one revolution the turning earth rotates on its axis approximately $365\frac{1}{4}$ times, thus determining the number of days in the year.

An imaginary plane passed through the sun and extended outward through all points in the earth's orbit is called the plane of the ecliptic. The axis of the earth's rotation has a position that is neither parallel with nor vertical to that plane. It has instead a fixed inclination of about $66\frac{1}{2}°$ from the plane of the ecliptic (or $23\frac{1}{2}°$ from vertical to it). This position is constant, and

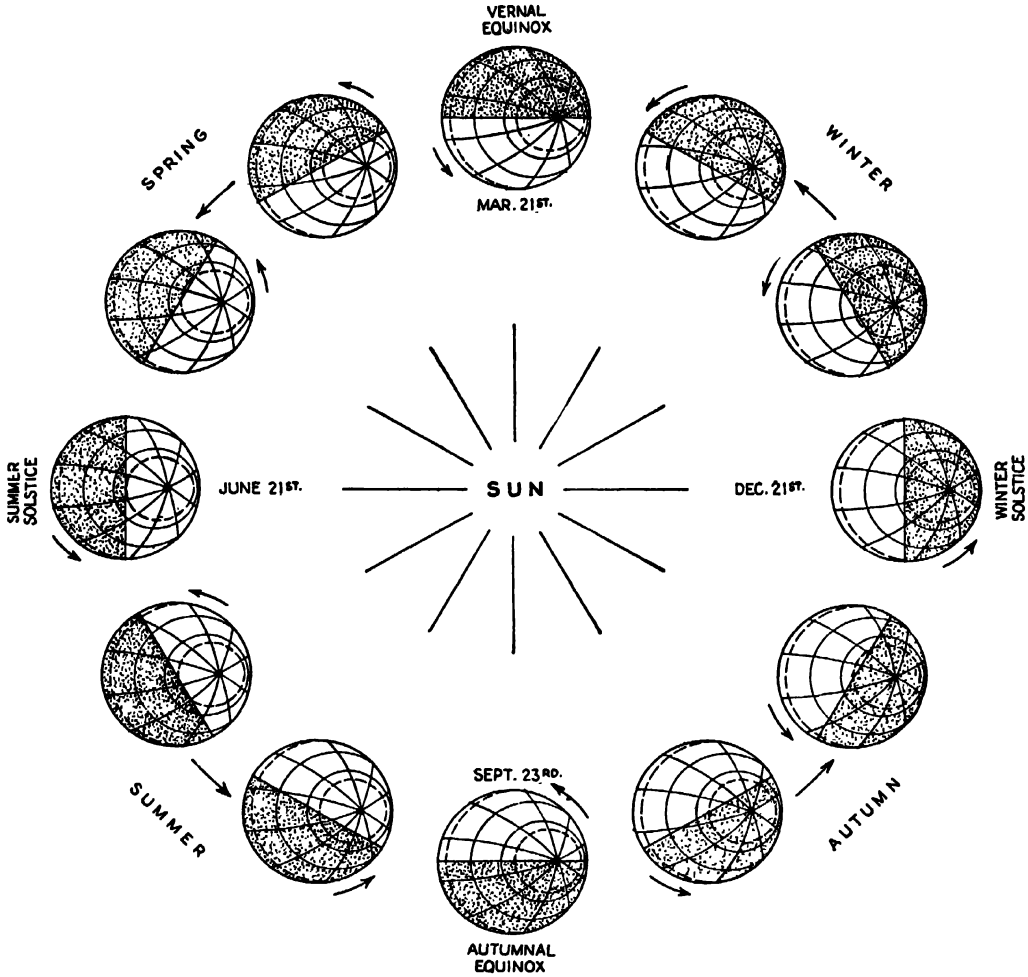

Fig. 1. The relation of the inclination of the earth's axis and its parallelism to the change of the seasons in the Northern Hemisphere.

therefore the axis at any time during the yearly revolution is parallel to the position that it occupied at any previous time (Fig. 1). This is called the parallelism of the axis.

The degree of *inclination* of the earth's axis and its *parallelism*, together with the earth's shape, its *rotation* on its axis, and its *revolution* about the sun, combine to produce several earth phenomena which are of vital importance among the conditions that surround earth inhabitants. Some of these are (*a*) the primary distribution of solar energy over the earth, (*b*) the changing of the seasons, and (*c*) the changing lengths of day and night. These matters, and others related to them, will be discussed more fully in their connection with climate.

LOCATION ON THE EARTH

13. The Earth Grid. The conditions described above also are matters of great impor-

tance in another way. They furnish a convenient means of determining and describing exactly the position or relative location of any place on the earth's surface. On a true sphere that is not in motion there is neither beginning nor ending, no natural point or line of reference from which to begin to measure the relative positions of other points. If it were not for its motions and other planetary relations, the earth also would have no natural point or line from which to measure direction. Since the fact of rotation establishes the geographic poles of the earth, these serve as initial points in a scheme of imaginary lines, called the earth grid, by means of which directions and relative locations are easily indicated. Midway between the poles an imaginary circle may be drawn upon the surface. It is a "great circle," called the *equator*. Other circles may be drawn at any desired distances from the poles. They will be smaller than the equator but parallel with it. They are called *parallels*. Upon the equator and the parallels, distance may be measured east or west from any given point. The north-south members of the earth grid, or system of coordinates, are called *meridians*. They are produced by drawing any number of circles which intersect at both poles. They are all great circles, and each of them bisects the equator and every parallel. Each of these great circles is divided at the poles and forms a pair of meridians, one meridian being a semicircle extending from North Pole to South Pole. By means of all these circles, the parallels and meridians, is developed the system of lines made familiar through the grid of a geographical globe.

14. Latitude. In the measurement of the earth it is customary to divide into quadrants the circle formed by each pair of meridians, the points of division being the poles and the two intersections with the equator. Each quadrant is divided into 90 parts, called degrees (°) of latitude, the sum of the number of degrees in the four parts being the 360 degrees of the meridian circle. The numbering of the degrees proceeds from the equator to either pole, and positions on the meridian are marked by the east-west cross lines of the parallels. By means of the parallels, latitude is reckoned from the equator (0°Lat.) northward to the North Pole (90°N.Lat.) on any meridian and, in the same way, from the equator to the South Pole (90°S.Lat.). Owing to the size of the earth, the average length of a degree of latitude is about 69 miles.

15. The Length of Degrees of Latitude. On a true sphere each degree of circumference, measured in any direction, has the same length, but this is not quite true on the earth. Because of the earth's polar flattening, degrees of latitude near the poles are slightly longer than those near the equator. The first degree of latitude from the equator has a length of 68.69 miles, while the first degree from the pole is 69.39 miles long. Each degree of latitude is divided into 60 minutes (′), and each minute into 60 seconds (″). One minute of latitude has an average length of 6,080 ft. (1 nautical mile) or about 1.15 statute miles, and one second of latitude is about 101 ft. The length of the meter, standard of measurement in the metric system, is, in theory, exactly one ten-millionth of the meridian distance from the equator to the pole.

The latitude of any place is determined by instrumental observation. It is necessary only, by means of the sextant, to measure the angle between the horizon and the zenithal position of the sun at noon. At the time of the equinoxes (about Mar. 21 and Sept. 22) the sun's rays at noon fall vertically on the equator, and the latitude of any place may be computed by subtracting from 90° the angle read on the sextant. For times other than the equinoxes the results obtained by the above method must be revised by the use of tables that show the different latitudes at which the rays of the sun fall vertically for each day in the year. Latitudes may be obtained also by instrumental observation upon the North Star (Polaris).

16. A parallel of latitude, drawn through points equally distant from the equator on all meridians, may be constructed for any degree, minute, or second of latitude. On an ordinary globe grid, at small scale, only a few of the many possible parallels are shown—usually those of the multiples of 5 or 10°. Almost always, how-

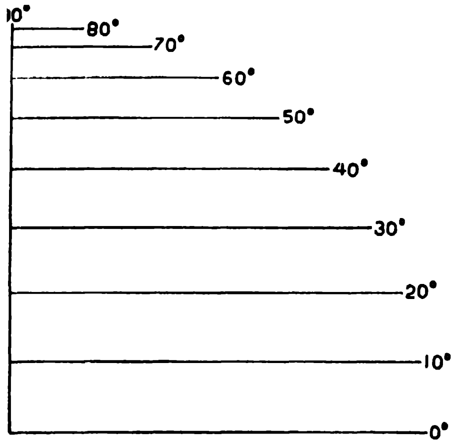

Fig. 2. The comparative lengths of the radii of the parallels.

ever, four fractional parallels are shown in addition to the others, because they have special significance. These are the parallels of approximately 23½°N. and S. and of 66½°N. and S., respectively. Their importance is derived from their relation to the inclination of the earth's axis to the plane of the ecliptic. The parallels of 23½°N. and S. are called the Tropics of Cancer and Capricorn, respectively. They mark the limits of that portion of the earth where the solar rays ever fall vertically (Fig. 1). The parallels of 66½°N. and S. are called, respectively, the Arctic and Antarctic Circles. They are the lines at which the midday rays of the sun are tangent to the earth's surface at the time of the shortest day of the year and at which the midnight rays are tangent at the time of the longest day (Fig. 15).

17. Longitude is reckoned east or west along the parallels of latitude. Just as distances on a horizontal chalk line are measured by the vertical lines on a rule, so positions on the east-west parallels of latitude are marked by the intersections of the north-south meridians of longitude. Among the meridians there is no particular one marked by nature (as is the equator for counting latitude) from which numbering may begin. All are exactly alike, and it is possible to begin to count from any one of them as 0°Long. This was in fact done for several centuries, each important country beginning with a meridian drawn through a spot within its own borders. So much confusion resulted that, in the year 1884, the meridian passing through the Royal Astronomical Observatory at Greenwich, near London, was chosen by international agreement as the zero meridian. It is called the *prime meridian.* It intersects the equator in the Gulf of Guinea at a point which has the distinction of having 0°00′00″Long. and 0°00′00″Lat. The 360° of longitude in the equator and each parallel are numbered 180°E. and 180°W. of the prime meridian to the opposite side of the earth.

18. Degrees of Longitude Vary in Length. All the parallels of latitude, except the equator, are less than great circles, the diameters of those near the poles being much less than that of the equator or of the other parallels near to it (Fig. 2). Since each parallel, regardless of its circumference, is divided into 360°, it follows that the length of 1° of longitude, in miles, must decrease toward the poles. One degree of longitude on the equator, a great circle, has about the same length as an average degree of latitude (69.15 miles). At latitude 30°N. or S. the length of a degree of longitude is 59.94 miles; at 60° it is 34.60 miles; at 80° it is 12.05 miles; and at the poles it is, of course, zero.

The longitude of an unmapped place east or west of the prime meridian, or of a ship at sea, can be determined only by finding the difference in time between that place and the prime meridian. This was first accomplished by means of accurate timepieces (chronometers) carried on shipboard and set at Greenwich, or prime-meridian, time. Observation of the sun at the instant when it reached the highest point (zenith) in its daily course across the sky gave local noontime, which could then be compared directly with the chronometer, and the difference in time translated into degrees and minutes of longitude. Now, instantaneous communication by telegraph and radio makes accurate time comparison possible almost everywhere and, therefore, makes possible greatly improved determinations of longitude. This is of particular aid in geographical exploration.

19. Accurate Location. The intersection of any two lines is a point; consequently, any point

on the earth's surface may be located by determining that it lies at the intersection of a certain meridian with a certain parallel. Therefore, by exact determination of its latitude and longitude the location of any place may be expressed briefly and with great accuracy. Thus if one were to say that the dome of the National Capitol at Washington was located at 38°53′-23″N.Lat. and 77°00′33″Long. west of Greenwich, one would state its exact position on the earth to within 10 paces.

20. Longitude and Time. The earth rotates eastward through its entire circumference of 360° of longitude in 24 hr., therefore through 15° in 1 hr. When noon (the zenith position of the sun) arrives at any meridian, it is already 1 hr. later (1:00 P.M.) on the meridian 15° east of that one, and it lacks 1 hr. of noon (11:00 A.M.) on the meridian 15° to the west of it. For the instant, it is noon on the one meridian only, but it is noon on that meridian from north pole to south pole. Four minutes later it is noon on the meridian 1° farther west. In a generation past, each town kept the time of its own meridian, which was called apparent solar time or, in common American parlance, "sun time." When rail transportation permitted rapid travel, it became awkward or impossible to change one's time a few minutes with every village passed. To avoid this necessity each railroad adopted an arbitrary time scheme which differed from that of most of the places that it passed through but was the same for considerable distances on the rail line. Unfortunately, several railroads in a region often adopted different times for their own use. Consequently, it sometimes happened that a town reached by different railroads found itself required to use, or distinguish between, several different kinds of time: its own solar time and one for each of its railways. The awkwardness and confusion of this situation led to the adoption by American railways, in 1883, of a system of *standard time*. This system, in theory, supposes that all parts of a north-south zone 15° of longitude in width adopt the solar time of the central meridian of that zone. Places within the zone that are east or west of the central meridian, instead of differing in time by a few minutes from it and from each other, all have the same time. Changes of time are then necessary only in crossing the boundary of the zone, and each change is exactly 1 hr. The timepiece is set forward (*i.e.*, later, as from 12:00 to 1:00) in traveling east and back (*i.e.*, earlier, as from 12:00 to 11:00) in traveling west. In practice, these zones are not bounded by meridians but by irregular lines the location of which is dictated by railway convenience and political consideration. Figure 3 shows the present standard-time zones of the United States.

On the whole earth there should be 24 standard-time zones, each extending from pole to pole and each differing from Greenwich time by an integral number of hours. In practice the arrangement is not quite so simple, for, although most countries follow the plan, certain isolated ones have not yet adopted standard time at all, and a few small countries employ standard meridians that are not multiples of 15 and therefore do not differ from Greenwich time by exact hours. For example, Netherlands time is 19 min. faster, and Bolivian time 4 hr. 33 min. (instead of 5 hr.) slower, than Greenwich time.

21. The International Date Line. The quickness with which the earth may be circumnavigated has introduced a problem of correction not only of the hour but also of the date and day of the week. The nature of this problem may clearly be seen if one imagines an airplane sufficiently fast to fly around the earth in the latitude of Chicago, let us say, in exactly 24 hr. If the flyer left Chicago, *going westward*, at noon

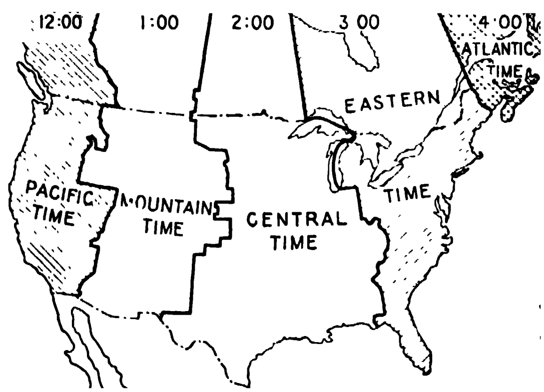

Fig. 3. The standard-time belts of the United States.

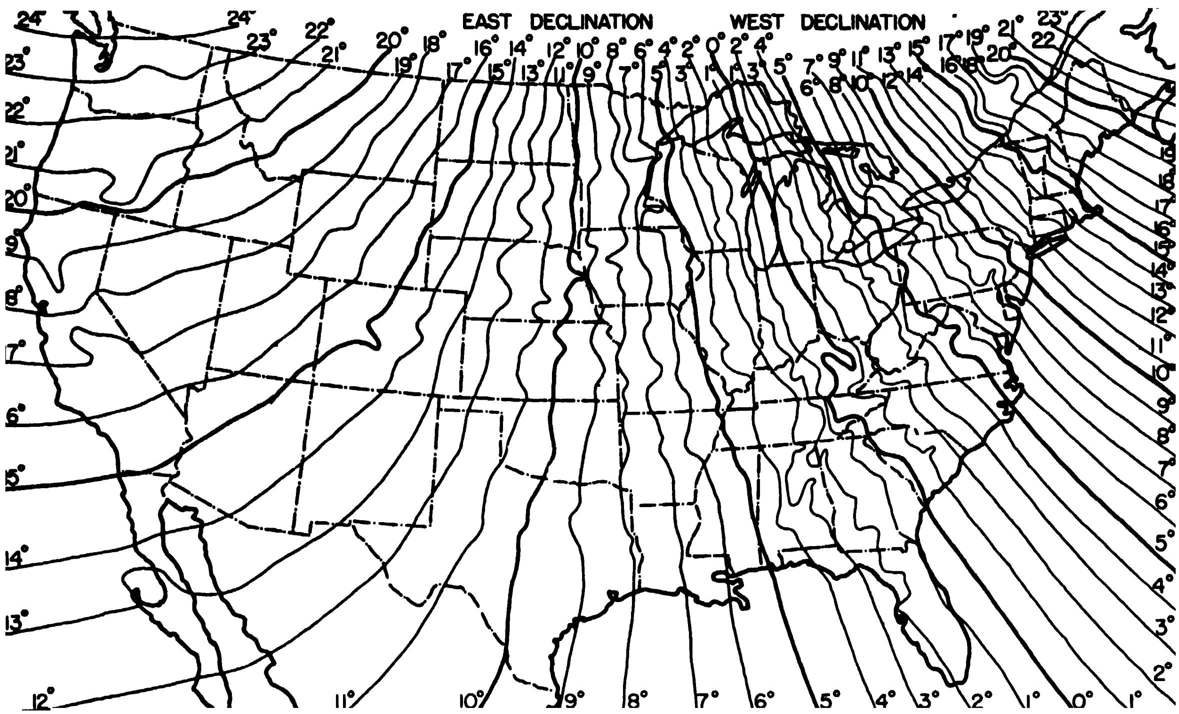

Fig. 4. Lines of equal magnetic declination (isogonic lines) in the United States. Only at points on the agonic line (0° declination) does the magnetic compass point true north. (*Generalized from a map by U.S. Coast and Geodetic Survey.*)

on Monday the tenth of the month, he would keep exact pace with the apparent motion of the sun, would see it in the same position all the way, and would return to Chicago the same (to him) noon. To persons in Chicago a night would have intervened, and it would be noon of Tuesday the eleventh. The flyer would have *lost* a day. If he had flown *eastward*, he would have encountered midnight over Spain, noon of another day over Central Asia, a second night over the Pacific Ocean, and would have returned to Chicago at noon of the second day, though he had been gone only 24 hr. To him it would be noon of Wednesday the twelfth, while to those who remained it is, as before, Tuesday the eleventh. The flyer has *gained* a day. The fact that one who travels slowly by train and boat loses or gains this time by 24 time corrections of 1 hr. each does not alter the case in the least. Unless he sets his calendar ahead one day when traveling around the earth westward and sets it back when traveling eastward, it will be out of adjustment on his return. To avoid the confusion that would result from individual choice as to place of change, an *international date line* has been established at the 180th meridian. There, correction may be made uniformly, and no correction of date is necessary unless that line is crossed. Certain deviations of the date line from the 180th meridian are agreed upon to prevent confusion of day and date in certain island groups or land areas that are divided by the meridian.

22. Direction. The location of places with respect to each other may be expressed in terms of direction and distance as well as by relative location in latitude and longitude. Direction usually is stated in terms that signify an angular relation (azimuth) to the meridian, or geographical north. Although, in recent years, the gyroscopic compass and other devices have made it possible to maintain direction by immediate reference to true north, yet much direction finding, especially in land surveys, still is accomplished by means of the magnetic compass. The needle of this instrument aligns itself

with the lines of magnetic force emanating from that great magnet the earth. However, the magnetic north and south poles are not opposite one another and even are subject to slight changes of position. In consequence, there are few places on the earth where the magnetic needle points true geographical north. At all other places the compass reads at an angle with true north. These angles vary considerably in size from place to place, and their amount is called the compass declination. Figure 4 shows the lines of equal compass declination in the United States. East of the line of zero declination the compass needle has a west declination, and west of the line it has east declination. In parts of the frequented oceans the compass declination is as much as 30 to 40° from true north. It is obvious that true direction cannot be found by the magnetic compass and that true maps cannot be made without a knowledge of the degree and direction of compass declination. This may be obtained by an observation on Polaris.

The Nature and Uses of Maps

23. Maps Are Essential Tools. Maps are graphic representations of the surface of the earth. They are used in many fields of learning but especially in earth sciences. For the student of geography *the map is an essential tool, a means of recording facts, and also a manner of expression.* Maps are almost infinite in number, size, form, and meaning, and they constitute almost a language in themselves. For their ready interpretation it is necessary that their important types and qualities be understood. To that end it is desirable that the student shall have a quick appreciation of at least three fundamental matters concerning all maps. These are (*a*) the size of the map representation compared with that part of the earth which it represents; (*b*) the nature of the plan, scheme, or "projection" employed in making the representation; and (*c*) the types of things represented on the map and the meanings of the various symbols or devices used to show them.

24. The Map Scale. A *globe* on which the continents and ocean basins are shown in modeled relief is the form of earth representation requiring the least interpretation. The dimensions of the globe may be measured, and the relation of its size to that of the earth, indicated in like units, may be expressed as a ratio. That ratio is called the *scale* of the globe. If, for example, a large globe has a diameter of 50 in. and a circumference of 157 in. (the diameter and the circumference of the earth being, respectively, about 500 million and 1,577 million inches), the ratio of the distance between any two places on the globe, measured in inches, to that between the same two places on the earth, measured also in inches, will be as 50 is to 500,000,000 or as 157 is to 1,577,000,000. That ratio is as 1 is to 10,000,000, and it is often written as a fraction, thus: $\frac{1}{10,000,000}$ or 1:10,000,000—and is called a fractional scale.

Maps, like globes, bear proportional relations to the parts of the earth that they represent. A statement of the proportion is printed on most maps in the form of a ratio or a fraction. It is called the *map scale.* Frequently the scale is expressed verbally also, or by means of a measured line. Maps may have large scales or small. A ratio of 1 to 10,000,000 indicates a small scale because one unit of map distance represents 10,000,000 units of earth distance, and the map is, by comparison, extremely small. A ratio of 1 to 100,000 indicates a map of much larger scale, and a ratio of 1 to 1 would indicate a map as large as the area mapped. Reference to a student's atlas will serve to illustrate the range of map scales ordinarily employed in such publications.

Between the application of scales to globes and to maps there is one essential difference. The scale of a globe, no matter how small, may truly be applied to it in any part and in any direction. On small-scale maps of large areas, especially of the entire earth, the indicated scale seldom is equally applicable to all the lines of the map, sometimes only to one of them. A reason for this will appear below.

25. The Nature of a Map. A map differs from a globe in that it is a representation of some part or all of the earth's curved surface on a

plane. A map may be made on a flat sheet of paper which will show a farm or the area of a village without distortion of shape or of relative area, because the part of the earth's spheroidal surface included in either of them is so small as to be itself practically flat. To make a map of the entire earth, a hemisphere, a continent, a state, or even a county without some degree of distortion is no more possible than it would be possible to press flat all or part of a slit tennis ball without stretching or tearing the rubber. *The only true representation of the whole earth is a globe.* The greater convenience of maps as compared with globes has led, however, to the invention of many systems of arrangement of the meridians and parallels of the earth grid in ways designed to control the unavoidable distortion as to its kind, degree, or place on the map. Such a systematic arrangement of lines is called a *map projection.*

26. Map Projections. The distortion of the earth's surface inherent in map projections is controlled by the mathematical arrangement of the lines of the grid in such ways that one or more of several objectives is attained. The map may (*a*) represent the *shapes* of limited areas correctly as compared with their shapes on a globe, (*b*) represent *areas* so truly that all parts of the map are in proper areal relation to the globe, (*c*) show *direction* correctly from some given point within the map or even from every point, or (*d*) show *distances* correctly from some point selected by the map maker. However, for advantages gained in one quality by mode of construction of the map projection some other quality must be sacrificed. *It is impossible for any map that shows a considerable part of the earth's surface to accomplish all these objectives at the same time*, and some accomplish none of them. For a more extended discussion of the nature of map projections and the appearance and properties of a few of their many forms the student is referred to Appendix B.

Representations on Maps

27. Classes of Map Devices. Maps are employed to show the areal distribution of many kinds of things. The devices used on the map to show distribution also are many. However, in a general way, they may be arranged in four groups which probably are not all-inclusive or even quite mutually exclusive. The groups are (*a*) devices employed to show areal extent, shape, or outline; (*b*) devices for showing patterns of arrangement; (*c*) devices intended to convey an impression of relative land elevation or surface relief; and (*d*) devices employed to show the areal distribution of statistical values of actual or relative quantity.

In the first group may be included all those familiar devices of line and color which characterize the many kinds of regional maps that show the extent or the boundaries of areas classified upon the basis of some kind of unity. These may be countries or other political divisions, areas of unity in geological formation, climatic type, landscape composition, or of any other nature. In the second group may be found maps of drainage patterns, city-street and road patterns, the patterns of other means of transportation and communication, and patterns of the distribution of towns and cities with respect to each other. In the third group are devices such as shadings and hachures (Fig. 298) arranged to produce the effect of light and shadow, simulating modeled relief on the earth. Some of these are of great intricacy and beauty and are the supreme examples of the map maker's skill (Fig. 5). In this group also is that useful device, the contour line, which is discussed more fully below. The fourth group includes many devices, prominent among them being such things as dots or squares, denoting area, or representations of cubes or spheres, indicating volume. Each of these is intended to convey the idea of the existence of a unit of number or value in a specific locality on the earth's surface. Maps having devices of this class are called *cartograms.* Their effectiveness as geographic tools is generally in inverse proportion to the size of the areal units for which the values are shown. Thus a few dots or squares, each representing a large unit of value and covering a large area, show generalities. Many of them, each representing a small unit of value and distributed prop-

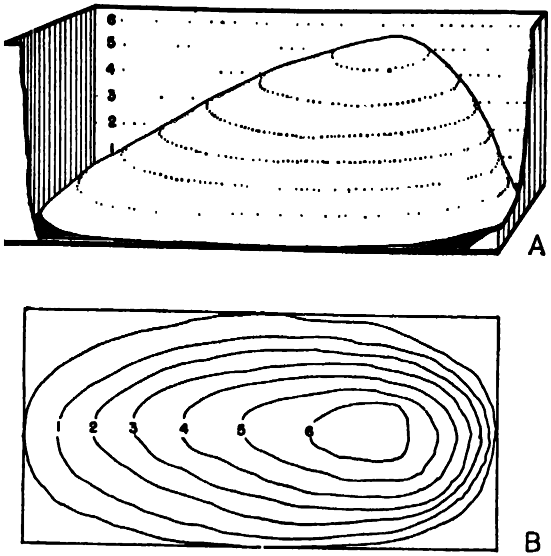

Fig. 8. Compare this diagram with a photograph of one of the United States topographic maps shown in Fig. 209.

On this little model the water levels, and therefore the contour lines, have a vertical separation of 1 in. This may be called the *contour interval.* If the pattern of the lines, as seen from above, is reproduced upon a sheet of paper, the result may be called a contour map, which, in this case, has a contour interval of 1 in. The lines may be numbered accordingly.

Few hills in nature are so smooth as this mound, and the example may be made more real by introducing a pair of gullies in its side (Fig. 9*A*). If the submergence is repeated, and the lines redrawn in the wax, it will be seen that in each gully the lines now follow along the gully side, cross its bottom, and return down its other side. If, now, the pattern of the lines, as viewed from above, is transferred to a map, it will look like Fig. 9*B*. From the arrangement of these lines further general facts may be learned. One is that when a contour line must cross a valley it does so by a bend such that the closed end of its loop points in the upslope direction. Conversely, contour lines bent so that their closed ends point in the upslope direction indicate gullies or valleys. Between the two gullies is a ridge. On the contour map of this hill the contour lines that emerge from the gullies and pass over the ridge appear to loop so that their bends point in the downslope direction. Thus, contour lines bent sharply toward the downslope direction always indicate ridges. An illustration of this principle is seen in Fig. 10, where natural contour lines are marked on a hill slope as a result of wave work performed in a reservoir at different stages in the lowering of the water level. On a map that represents the irregular surface of a region these same principles may be applied.

30. Interpretation of United States Topographic Maps. Although some countries use shaded représentations of surface configuration on their official maps, the topographic maps of the U.S. Geological Survey depend wholly upon contour lines to produce the effect of surface relief. These maps are now available for about half the area of the country (Fig. 11), and their use provides so much pleasure and profit that every educated person should be able to interpret them.

The maps are printed in either three or four colors, each having a restricted meaning. In *black* are shown those features in the surveyed area that may be classed as culture, *i.e.*, have human origin. In this color are roads, houses, towns, place names, boundary lines, and parallels and meridians. In *blue* are printed all water features, both natural and man-made, such as canals, streams, marshes, millponds, lakes, or

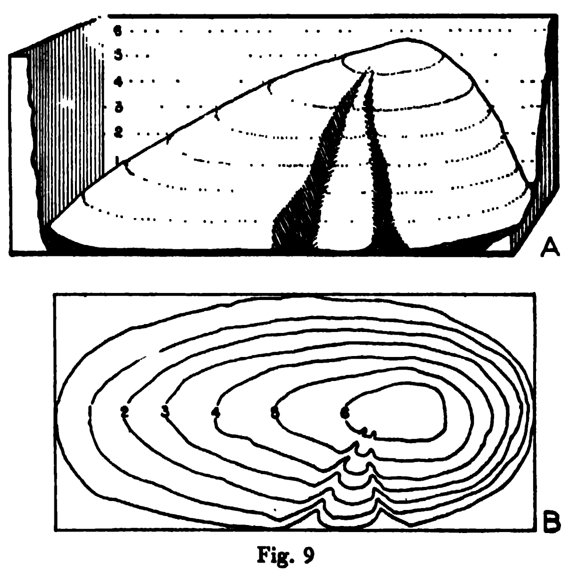

Fig. 9

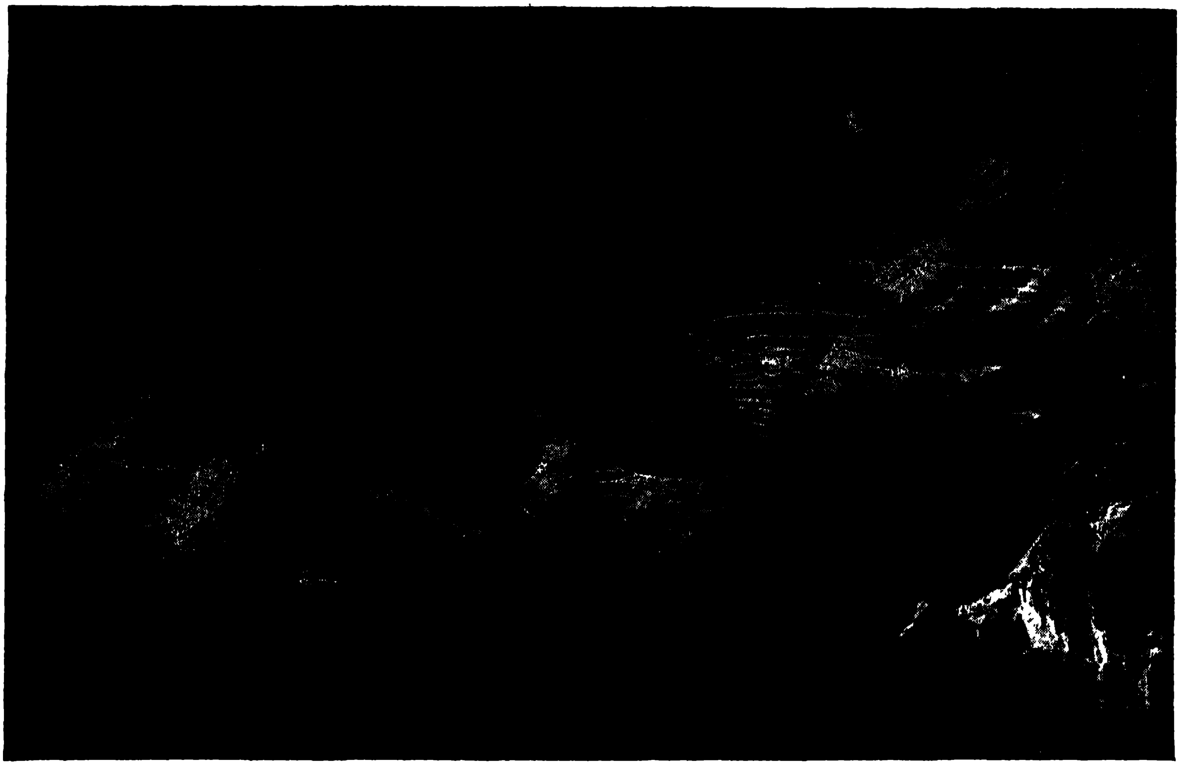

Fig. 10. Nature's contours on an emerging shore. Wave-cut lines on a hilly slope, resulting from the intermittent withdrawal of water from an irrigation reservoir. (*Courtesy of Taylor-Rochester.*)

seas. The various classes of such features are distinguished by appropriate symbols in blue. In *green*, if that color is shown, are areas covered by timber or woodland. This feature is shown on a small number of the published maps only. The contour lines and other symbols relating to the relative elevation of the land surface are shown in *brown*.

Each map is provided with a place title and with parallels and meridians that indicate its exact location and extent. Each is provided also with a scale and with a statement of the contour interval used on that map. The contour lines express the elevation of the land, in feet, above a datum plane which is mean sea level. To facilitate the reading of these brown contour lines, which often are very closely spaced, it is customary to make every fifth line heavy and to open it at intervals for the insertion of its numerical value. The intervening four lines are drawn lightly and are not numbered. Their values may be obtained by using the contour interval as a unit and counting from the nearest numbered line. If it is desired to know the height of any feature, such as that of a hill above its adjacent valley, it may be approximated by multiplying the number of contour intervals between the two points by the value of the contour interval. An error of nearly twice the contour interval is possible in this instance because of uncertainty as to just how far below the lowest contour line the valley bottom lies and how far above the highest line the hilltop extends. In each surveyed area a few carefully measured points are given permanent markers in the form of numbered metal posts called *bench marks*. The location of each of these is shown on the map of the area by the letters B.M. and figures showing its exact elevation, printed in black.

The standard United States topographic sheet includes a quadrangle of 0°15′ of latitude and 0°15′ of longitude. It is printed at a scale of 1/62,500, or approximately 1 in. to 1 mile. Some

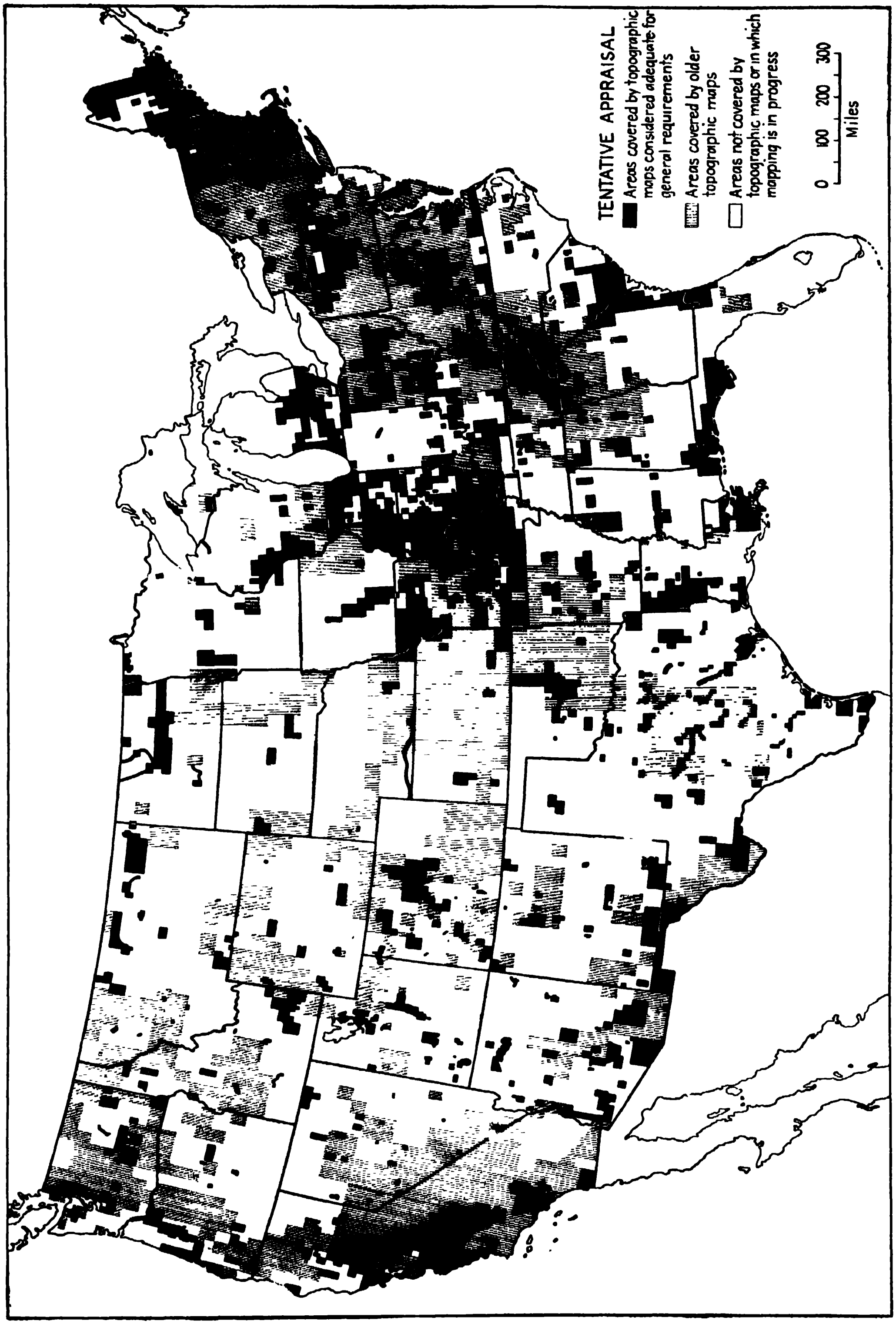

Fig. 11. Topographic maps by the U.S. Geological Survey are available for only about half the area of the United States, and of those available less than half are recent or generally adequate. (*After U.S. Geological Survey.*)

maps are printed at about twice that scale, 1/31,680 (2 in. = 1 mile), and show only one-fourth as much area. Still others are printed at one-half the standard scale, 1/125,000 (1 in. = 2 miles), and show four times as much area as the standard maps (about sixteen times as much as those at 1/31,680). A few maps are printed at still other scales. The contour intervals employed usually are 10, 20, 50, or 100 ft. On maps of extremely flat land, intervals as small as 5 ft., or even 1 ft., are used; but on maps of rugged mountains, intervals are sometimes as much as 250 ft. Both the map scale and the contour interval of *each map* must be read and considered before its true meaning can be interpreted.

If the above principles are used, it is not difficult to read the essential relief features of the ordinary topographic map. Facility in their interpretation, however, comes only with experience. In chapters to follow, the nature and arrangement of many of the landforms to be described can be made much more clear and real if the text is supplemented by selected maps from the United States topographic atlas. Although the nature of this book does not permit the inclusion of representative maps illustrating the various features discussed, specific topographic quadrangles which do illustrate them are indicated in Appendix D. It is hoped that some of these at least may be made available and that the student will acquire sufficient ability to read them so that they may make their full contribution to his understanding of the element of landforms in the natural environment.

PART ONE

The Physical Elements of Geography

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CHAPTER 3: *Air Temperature (Including Insolation)*

Sun Energy or Insolation

35. Source of Atmospheric Heat. The sun, which is one of the smaller stars of the universe, is the only significant source of heat for the earth's atmosphere. Out into space from this gigantic body, whose diameter is more than one hundred times the earth's and whose surface is estimated to have a temperature of about 10,300°F., streams a tremendous mass of energy. The earth, nearly 93 million miles distant, intercepts less than 1/2,000,000,000 part of the solar output. Yet to this small percentage of the sun's total energy many of the physical, and all of the biotic, phenomena of the earth owe their existence. The radiant energy received from the sun, transmitted in the form of short waves (1/10,000 to 1/100,000 in. in length) and traveling at the rate of 186,000 miles a second, is called *solar radiation*, or *insolation*. A considerable part of the solar-radiation spectrum can be perceived as light. But there are other waves, some shorter (ultraviolet) and others longer (infrared), which cannot be seen. Since sun radiation is the single important source of atmospheric heat, its distribution over the earth is of primary significance, for all weather and climatic phenomena can be traced directly or indirectly to the amounts of insolation received at different parts of the earth. Among the several controls of climate, none approaches sun or insolation in importance.

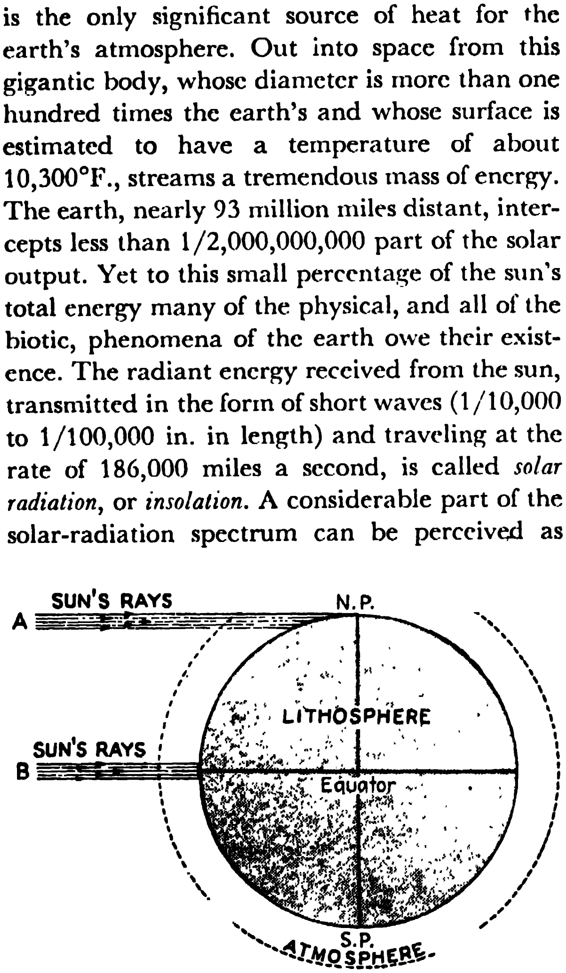


Fig. 12. The oblique ray (*A*) delivers less energy at the earth's surface than the vertical ray (*B*) because its energy is spread over a larger surface and likewise because it passes through a thicker layer of absorbing and reflecting atmosphere.

36. Major Factors Determining the Amount of Solar Radiation Received at Any Portion of the Earth's Surface. Omitting for the moment the effects of an atmosphere, the amount of solar energy that any portion of the earth's surface receives will depend primarily upon two factors: (*a*) *the angle at which the rays of sunlight reach the earth* and (*b*) *the duration of solar radiation*, or *length of day*. Because an oblique solar ray is spread out over a larger surface than a vertical one, it delivers less energy per unit area (Fig. 12). Moreover, although for the moment the effects of an atmosphere are being omitted, it may be added that an oblique ray also passes through a considerably thicker layer of scattering, absorbing, and reflecting air. Winter sunlight, therefore, is much weaker than that of summer, since in late December the noon sun at Madison, Wis., located at 43°N., is only 23½° above the horizon, whereas in late June it has an elevation of 70½°. As regards the second item, it would seem to require no further explanation of the fact that the longer the sun shines (length of day), the greater the amount of solar energy received, all other conditions being equal. Thus the longest summer days (15+ hr.) in the latitude of southern Wisconsin, which have 6+ hr. more of daylight than the shortest winter days (9− hr.),

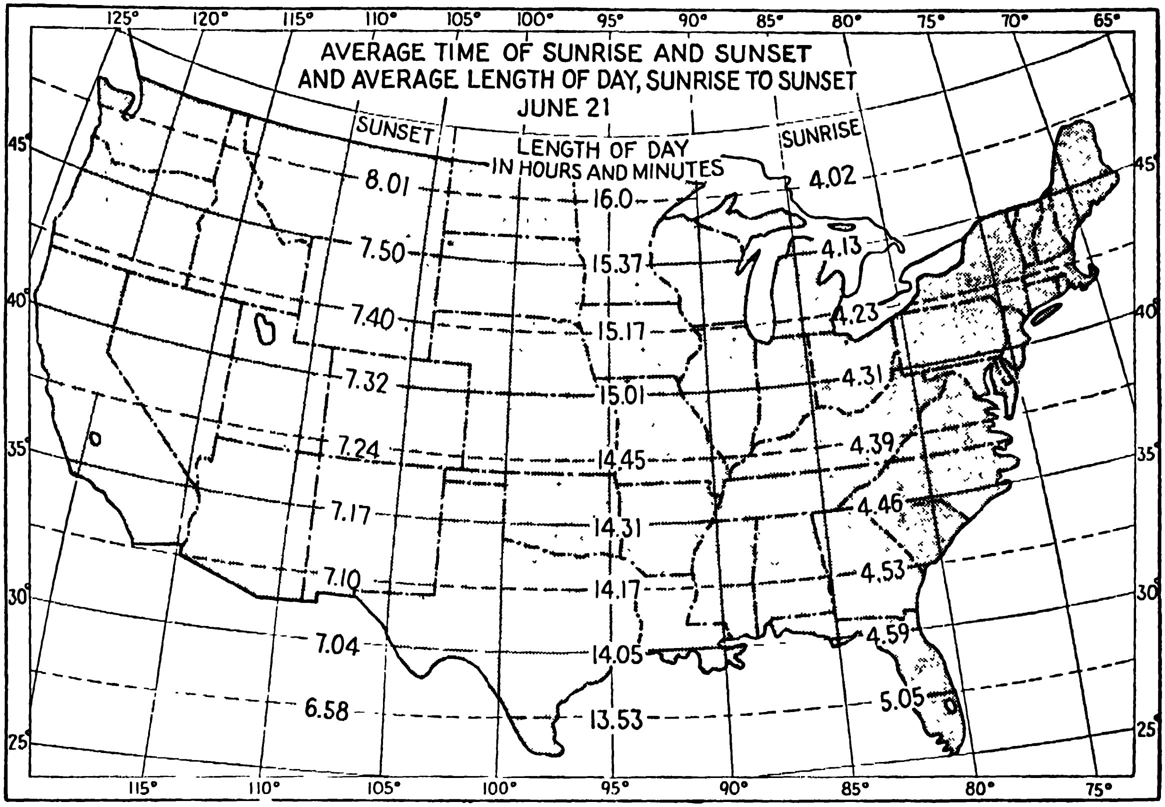


Fig. 13

allow for much greater receipts of solar energy (Figs. 13 and 14). It is quite understandable, then, why in these latitudes summer temperatures are so much higher than winter temperatures, since (*a*) sun's rays are less oblique, and (*b*) days are much longer in summer.

Since along any parallel the length of day and the angle of the sun's rays are equal, it follows that all parts of a parallel (except for differences in the transparency of the atmosphere) receive identical amounts of insolation. Similarly, different parallels or latitudes receive unlike amounts of solar radiation, the annual amount decreasing from equator to poles. If solar energy were the only control of weather and climate, all places in the same latitude should have identical climates. Although certainly not identical throughout, the strong climatic resemblances within latitude belts testify to the dominant, although not exclusive, rank of sun control.

37. Earth and Sun Relations. The rotation and revolution of the earth and the inclination and parallelism of its axis have been discussed in an earlier chapter (2). It remains to be analyzed, then, how these earth motions and positions act to produce the changing lengths of day and varying angles of the sun's rays, which in turn are the causes of the seasons.

Length of the Longest Day (Hence Also of the Longest Night) at Certain Latitudes

Latitude	0°	17°	41°	49°	63°	66½°	67°21′	69°51′	78°11′	90°
Duration	12 hr.	13 hr.	15 hr.	16 hr.	20 hr.	24 hr.	1 mo.	2 mo.	4 mo.	6 mo.

38. *The Equinoxes; Spring and Fall.* Twice during the yearly period of revolution, on Mar. 21 and Sept. 23, the sun's noon rays are directly overhead or vertical at the equator (Fig. 15). At these times, therefore, the circle of illumination, marking the position of the tangent rays, passes through both poles and consequently cuts all the earth's parallels exactly in half. One half of

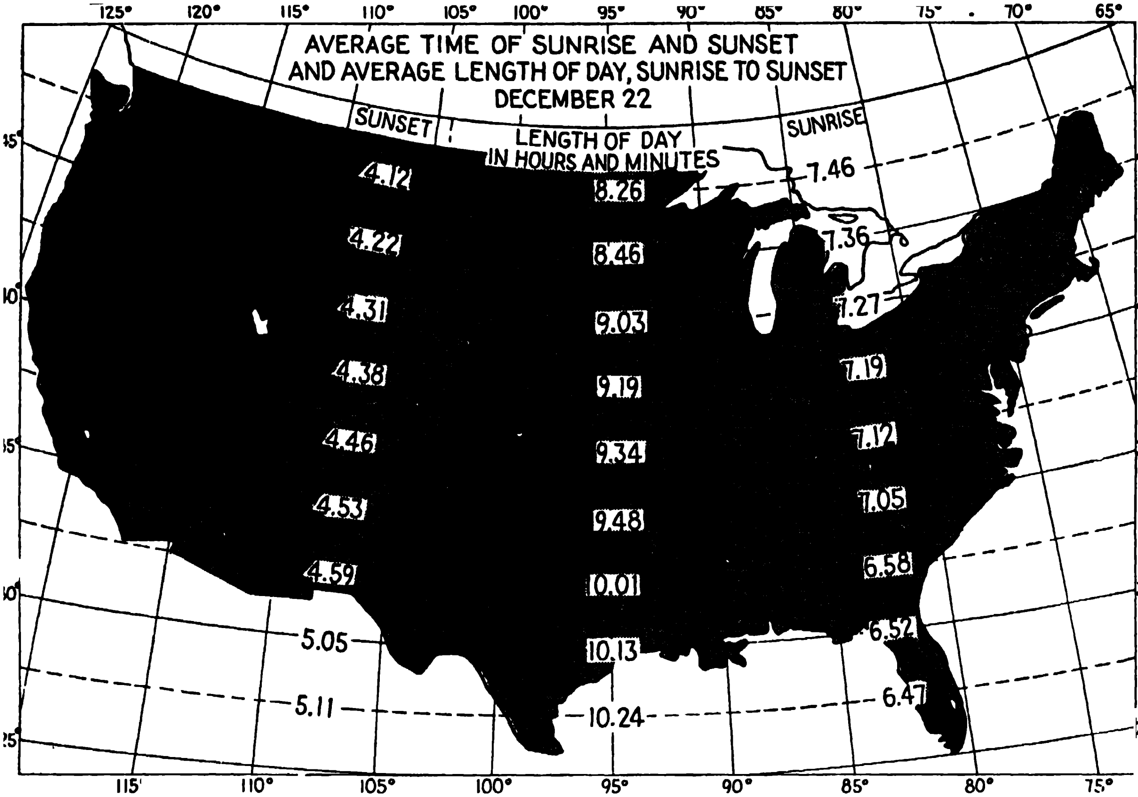


Fig. 14

each parallel (180°) consequently is in light, and the other half in darkness. For this reason, since the path described by any point on the earth's surface during the period of rotation is coincident with its parallel of latitude, days and nights are equal (12 hr. each) over the entire earth. From this fact the two dates Mar. 21 and Sept. 23 get their names, the *equinoxes* (spring equinox Mar. 21, autumn equinox Sept. 23—Northern Hemisphere). At these seasons the maximum solar energy is being received at the equator, a latitude from which it diminishes regularly toward either pole, where it becomes zero.

39. *The Solstices; Summer and Winter.* On June 22 the earth is approximately midway in its orbit between the equinoctial positions, and the North Pole is inclined 23½° *toward* the sun (Fig. 15). As a result of the axial inclination, the sun's rays are shifted northward by that same amount (23½°), so that the noon rays are vertical at the Tropic of Cancer (23½°N.), and the tangent rays in the Northern Hemisphere pass over the pole and reach the Arctic Circle (66½°N.), 23½° on the opposite side of it. In the Southern Hemisphere the tangent rays do not reach the pole but terminate at the Antarctic Circle, 23½° short of it. Thus while all parts of the earth north of the Arctic Circle are experiencing constant daylight, similar latitudes in the Southern Hemisphere (poleward from the Antarctic Circle) are entirely without sunlight. At this time, June 22, or the *summer solstice*, all parallels, except the equator, are cut unequally by the circle of illumination, those in the Northern Hemisphere having the larger parts of their circumferences toward the sun so that days are longer than nights. Longer days, plus a greater angle of the sun's rays, result in a maximum receipt of solar energy in the Northern Hemisphere at this time. Summer, with its associated high temperatures, is the result, and north of the equator June 22 is known as the summer solstice.

In the Southern Hemisphere at this same time, all these conditions are reversed, nights being longer than days and the sun's rays relatively oblique, so that solar radiation is at a minimum and winter conditions prevail.

On Dec. 22, when the earth is in the opposite position in its orbit from what it was on June 22, it is the South Pole that is inclined 23½° *toward* the sun (Fig. 15). The latter's noon rays are then vertical over the Tropic of Capricorn (23½°S.), and the tangent rays pass 23½° over the South Pole to the Antarctic Circle (66½°S.). Consequently, south of 66½°S. there is constant light, while north of 66½°N. there is a continuous absence of sunlight. All parallels of the earth, except the equator, are cut unequally by the circle of illumination, with days longer and sun's rays more nearly vertical in the Southern Hemi-

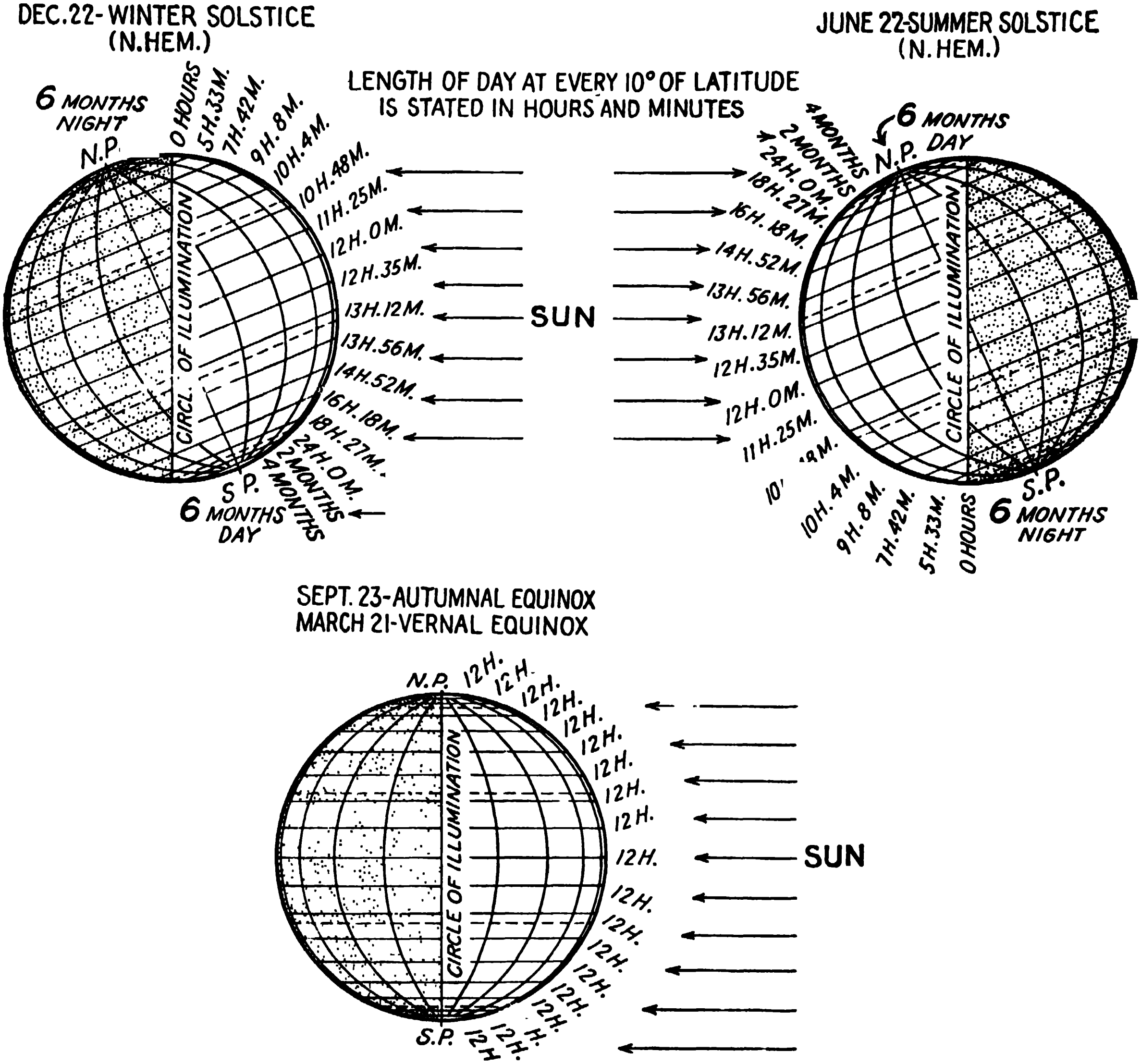


Fig. 15. On the equinoxes, when the sun's vertical rays are at the equator, the circle of illumination cuts all the parallels in half, and days and nights are equal in length over the entire earth. At this time insolation decreases regularly from equator to poles. At the times of the solstices the sun's vertical rays have reached their greatest poleward migration. The circle of illumination cuts all the parallels (except the equator) unequally so that days and nights are unequal in length except at latitude 0°.

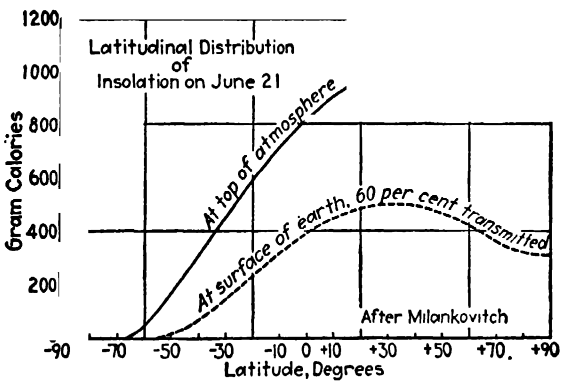


Fig. 16

sphere. This, therefore, is summer south of the equator but winter in the Northern Hemisphere (winter solstice), where opposite conditions prevail.

40. Distribution of Solar Radiation at the Earth's Surface. *Effects of an Atmosphere Omitted.* It is clear from the previous discussion that the belt of maximum insolation swings back and forth across the equator during the course of a year, following the shifting rays of the sun, with the two variables, (*a*) angle of sun's rays and (*b*) length of day, largely determining the amount of solar energy received at any time or place.

41. *Distribution from Pole to Pole along a Meridian.* For the *year as a whole* insolation is highest at the equator and diminishes with regularity toward the poles (table below), at which points it amounts to about 40 per cent of that at the equator. The distribution is similar at the time of the two *equinoxes* except that insolation declines to zero at the poles (Fig. 15). This symmetrical latitudinal distribution of solar radiation at the time of the equinoxes is of great importance climatically. It is in the transition seasons of spring and fall when the Northern and Southern Hemispheres are receiving approximately equal amounts of insolation that temperature conditions in the two hemispheres are most nearly alike. Similarly, pressure, wind, and precipitation conditions, and as a result the over-all weather situation, is more in balance to the north and south of the equator. Significantly, world temperature, pressure, wind, and precipitation-distribution patterns for spring and fall bear close resemblances to the average annual patterns for these same climatic elements.

Total Annual Insolation for Various Latitudes Expressed in Thermal Days

(Effects of an atmosphere omitted)

(The Unit, or Thermal Day, Is the Average Total Daily Insolation at the Equator)

Latitude	*Thermal Days*
0°	365.2
10°	360.2
20°	345.2
30°	321.0
40°	288.5
50°	249.7
60°	207.8
70°	173.0
80°	156.6
90°	151.6

time of the two solstices (June 22 and Dec. 22), when the sun's noon rays are vertical 23½° poleward from the equator and the length of day increases toward the pole where it reaches a maximum, the latitudinal distribution of insolation is very asymmetrically developed, with the summer hemisphere receiving two to three times the amount of the winter hemisphere (Fig. 16).[1] Omitting the effects of an atmosphere, insolation reaches a maximum at the North Pole on June 22, although the amount is high throughout the Northern Hemisphere from about latitude 30° poleward. The more realistic representation of insolation distribution, with the absorptive and reflective effects of an atmosphere considered (Fig. 16), still shows the maximum insolation to be in the lower middle latitudes (30°–40°), and latitude 60° receives nearly the same amount as the equator. The much steeper latitudinal insolation gradient in the winter hemisphere as compared with the summer hemisphere is a striking feature of insolation distribution (Fig. 16). The above described characteristics of solar-radiation distribution at the times of the solstices, which times represent the extreme seasons of summer and

[1] By "summer hemisphere" is meant the hemisphere that has summer. Thus the Northern Hemisphere would be the summer hemisphere in July and the Southern Hemisphere would be the summer hemisphere in January.

winter, provide the basic explanations for many of the earth's larger features of weather and climate. Some of the latter are (*a*) the marked north-south migration of the temperature, wind, and precipitation belts following a similar migration of insolation belts; (*b*) the warm-to-hot summers of the middle latitudes where insolation reaches a maximum for the summer hemisphere; (*c*) the much steeper temperature gradients in the winter hemisphere as compared with the summer hemisphere; and (*d*) the greater storminess and weather variability in the former.

42. Annual Distribution of Insolation for Various Latitudes. The yearly insolation curves for the several latitudes can be arranged in three general groups (Fig. 17): (*a*) The tropical or low-latitude type, which prevails in those regions between the Tropics of Cancer and Capricorn, is constantly high and varies little throughout the year. This feature accounts for the constant heat of the tropics. Since during the course of a year all regions between the two tropics are passed over twice by the vertical rays of the sun, the insolation curve for low latitudes contains two maxima and two minima. (*b*) The middle-latitude type, on the other hand, has a single maximum, and as in the tropics, insolation at no time declines to zero. (*c*) The polar type, *i.e.* poleward from the Arctic and Antarctic Circles, also has but one maximum and one minimum period of insolation, but unlike the other latitudes there is a portion of the year when direct sunlight is completely absent. For this reason, the insolation curve for the high latitudes declines to zero.

43. *Effects of an Atmosphere upon Insolation.* Thus far the whole problem of insolation distribution has been greatly simplified by assuming that solar radiation is received at the earth's surface without passing through an atmosphere. When that gaseous envelope is added, numerous modifications and complications result. Chief among these is a weakening of insolation at the earth's surface due to (*a*) *selective scattering*, chiefly of the short wave lengths of blue light by very small obscuring particles (molecules of air, fine dust); (*b*) *diffuse reflection* of all wave lengths by larger particles (dust, cloud droplets); and (*c*) *absorption* of selected wave lengths chiefly by water vapor (see solid lines in Fig. 17). A part of that energy which is scattered and reflected is sent back into space and is lost to the earth. Some of it, however, reaches the earth's surface in the form of diffuse blue light of the sky, called diffuse daylight, and is transformed into heat and other forms of energy. It is this diffuse daylight which prevents absolute darkness on cloudy

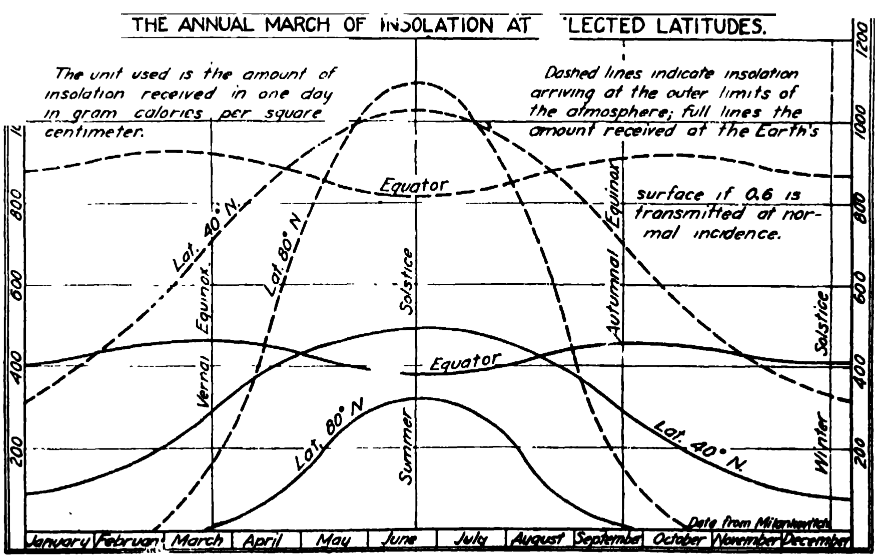


Fig. 17

days, indoors, or in the shade where direct sunlight is absent. The energy transmitted to the earth in this form probably amounts to one-quarter of the energy of direct sunlight.

The amount of depletion of insolation by reflection and absorption in passing through the atmosphere depends upon (*a*) the length of the passage, or, in other words, the angle of the sun's rays; and (*b*) the transparency of the atmosphere. The former factor can be arrived at mathematically, but the second is variable according to time and place. It is estimated that 42 per cent of the total insolation reaching the outer limits of the air layer is lost by *scattering and reflection* from clouds, small dust particles, molecules of air, and the earth's surface and so has no part in heating either the earth or its atmosphere. Fifteen per cent is *absorbed* directly by the atmosphere, most of it by water vapor. The remaining 43 per cent reaches the earth's surface either as direct sunlight or as diffuse daylight, is absorbed by it, heats it, and eventually heats the atmosphere as well. From the preceding analysis it is obvious that only some 58 per cent of the solar radiation (15 per cent absorbed by the atmosphere directly and 43 per cent absorbed by the earth's surface) is available for heating the atmosphere.

Absorption of Insolation at the Earth's Surface; Processes Associated with the Heating and Cooling of the Earth's Surface and Atmosphere

HEATING AND COOLING OF LAND AND WATER SURFACES

44. Land and Water Contrasts. Thus far the discussion has been concerned largely with distribution of solar energy, the single important source of atmospheric heat. But sun energy is of such short wave lengths that only relatively small amounts (15 per cent) of it can be absorbed directly by the earth's atmosphere. Perhaps, on the average, as much as half the solar energy slips through the atmosphere and reaches the surface of the earth, although to be sure, a part of this is reflected back again, leaving only about 43 per cent as effective in heating the earth's surface.

All bodies whatever their temperature give off radiation. The hotter the body, the more intense the radiation and the shorter the wave lengths. Low-temperature long-wave radiation like that of the earth is invisible, whereas much of the sun's high-temperature short-wave radiation is visible. In order to be readily absorbed by the air, sun energy first must be converted into terrestrial energy, which is composed of longer wave lengths. (Ratio of wave lengths of solar and terrestrial energy is roughly 1 to 25.) This conversion from short-wave solar to long-wave terrestrial energy takes place principally at the earth's surface, by which insolation is much more readily absorbed than it is by the relatively transparent atmosphere. Absorbed at the earth's surface, the solar energy is there converted into heat, after which the earth itself becomes a radiating body. Thus the atmosphere receives most of its heat only *indirectly* from the sun but *directly* from the earth's surface, which in turn had previously absorbed and consequently been warmed by solar energy. It is obvious, therefore, that preliminary to a discussion of heating and cooling the atmosphere, it is necessary to understand the comparative reactions to solar energy (in terms of reflection, absorption, transmission) of the various kinds of terrestrial surfaces. Here the greatest contrasts are between land and water surfaces, although to be sure, there are no fixed values for all land areas, because of such variables as snow cover, soil color, and vegetation color.

Land and water surfaces with identical amounts of insolation falling upon them do not acquire similar temperatures, nor do they cool at the same rate. The primary reason for this contrast is related to the fluid character of water. Vertical convection currents, together with waves, drifts, surface currents, and tides, tend to distribute the absorbed solar energy throughout a large mass of water. As a consequence the surface temperatures of the water do not rise rapidly. Land, on the other hand, is unable to distribute the absorbed solar energy throughout a large volume, with the result that the land

surface acquires a higher temperature. It is this ability of water to distribute heat gains and losses at the surface throughout a large volume that accounts for its greater conservativeness in temperature changes as compared with land.

A supplementary, although less important, factor is the relatively much greater transparency of water as compared with land. The sun's rays are able to penetrate a water body to considerable depths, with the result that energy is distributed throughout a larger mass. On the other hand, the opaque land concentrates the sun energy close to the surface, which results in more rapid and intense heating. This same concentration of the energy close to the surface likewise permits the land area to cool more rapidly than is true of a deeply warmed water body. Also of some significance is the fact that the *specific heat* of water is higher than that of land. In other words, it requires only about one-fifth as much energy to raise a given volume of dry earth by one degree as it does an equal volume of water. For the earth as a whole, the losses of solar energy by reflection from land and water surfaces are not greatly different, so that reflection is not a significant item in the heating and cooling contrasts of land and water surfaces. It is of considerable importance, however, in determining the surface temperatures of land surfaces with contrasting reflecting powers.

From the above comparisons of land and water as regards their reactions to insolation, it becomes evident that land-controlled, or continental, climates should be characterized by large daily and seasonal extremes of temperature, whereas ocean-controlled, or marine, climates should be more moderate. The ocean surface probably changes temperature not more than 1° between day and night, and seasonal changes also are very small. The relatively slower heating and cooling of water bodies quite naturally lead to a lag in the seasonal temperatures of marine climates.

HEATING AND COOLING THE ATMOSPHERE (TYPES OF HEAT TRANSFER)

45. Being acquainted now, as a result of the previous discussion, with (*a*) the distribution of solar energy over the earth and (*b*) the contrasting reactions of land and water surfaces to this solar energy, and (*c*) being aware that the air receives most of its energy directly from the surface upon which it rests and only indirectly from the sun, the background is sufficient to proceed with an analysis of the processes involved in heating and cooling the atmosphere.

46. Absorption of Direct and Reflected Insolation. The earth's atmosphere is relatively transparent to direct and reflected solar radiation, which is short-wave energy, only about 15 per cent being absorbed, and that chiefly by small amounts of water vapor. About one-half of this absorption takes place in the lower two kilometers of air, but this is a large mass of air through which to spread 7½ per cent of the solar radiation. The process is not very effective therefore in producing the normal daytime rise in temperature close to the earth's surface. Evidence of this is suggested by the fact that often on a clear winter day, when the land surface is blanketed by a reflecting snow cover, air temperatures may remain extremely low in spite of a bright sun. At the same time, on the south side of an absorbing brick wall or building, where short-wave sun energy is being converted into long-wave terrestrial energy, it may be comfortably warm. Dust, an impurity in the air, readily absorbs insolation, each particle thereby becoming a tiny focus for radiated terrestrial energy

47. Conduction. When two bodies of unequal temperature are in *contact* with one another, energy in the form of heat passes from the warmer to the colder object until they both attain the same temperature. Thus, during the daylight hours, the solid earth (without a snow cover), being a much better absorber of insolation than air, attains a higher temperature. By conduction, therefore, the layer of air resting upon the warmer earth becomes heated. But air is a poor conductor, so that heat from the warmed lower layer is transferred very slowly to those above. Unless there is, through movement, a constant replacement of the warmed layer in contact with the earth, only the lower few feet will be heated by this process during

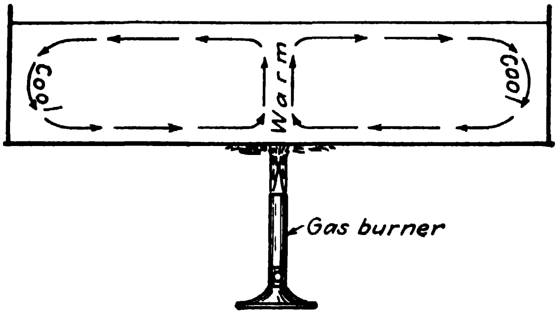


Fig. 18. Representation of a convectional circulation.

the course of a day. Through air currents and winds, however, more air is brought into contact with the heated earth's surface and consequently is warmed. Heating by conduction is primarily a daytime and a summer process.

Just as a warm earth on a summer day heats the air layer next to it by conduction, so a cold earth, chilled by terrestrial radiation on a winter night, has exactly the opposite effect. The earth cools more rapidly than the atmosphere because it is a more efficient radiator of energy. It not infrequently happens that, during clear, calm winter nights, as a result of radiation and conduction, the atmospheric strata adjacent to the earth become colder than those at some distance above its surface (55). In general, heat transfer by conduction in the atmosphere is very unimportant compared with the other processes.

48. Vertical Convection. Convection involves the transfer of heat through movement of the air itself. One of the commonest forms of convection results when the surface air, as a result of being heated by conduction and radiation, expands in volume and consequently decreases in density. Because of expansion, a portion of the warmer, lighter column of air overflows aloft, thereby decreasing its own pressure at the surface and at the same time increasing that of the adjacent cooler air. This causes a lifting of the warmer, lighter air column by the heavier, cooler settling air that flows in at the surface to displace it. Such a circulation, as described above and illustrated in Fig. 18, is called a *convectional system*. Warm surface air, expanded, and therefore less dense, is like a cork that is held under water; *i.e.*, it is unstable and inclined to rise. This convectional principle (which applies to liquids and gases only) is employed in the ordinary hot-air and hot-water heating systems. The rising masses of warmed air on a hot summer day make air transport relatively bumpy, since the plane alternately crosses rising and sinking air masses.

Still another form of vertical convective transport is the mechanical turbulence caused by wind action. This type of vertical movement is particularly well developed in strong gusty winds and is further increased by rough terrain. An additional phase of the convective system with its vertical transport of heat involves evaporation and condensation. When water is evaporated at the earth's surface, the large amounts of heat energy consumed by the process are removed from the earth and carried aloft as latent heat in the water vapor. When the water vapor condenses to form clouds, this latent energy is released into the atmosphere and warms it.

49. Importation by Air Masses and Winds. Although in physics convection is understood to involve the transfer of heat by either vertical or horizontal mass motions, as the term applies to the atmosphere it usually denotes vertical movement. The much larger horizontal transfer of heat by winds and air masses is called *advection*. Considering the earth as a whole this is the most important means of heat transfer. Moreover, it is this advection of air masses that causes most of the day-to-day weather changes and the storminess of winter climates in the middle latitudes. Even the layman has come to recognize that in Northern Hemisphere middle latitudes a south wind is usually associated with unseasonably high temperatures. In such a case the wind acts simply as the conveyer or importer of heat from lower latitudes where insolation is greater and higher temperatures are normal. Such an importation of southerly warmth in winter results in mild weather, with melting snow and sloppy streets. In summer, several days of south wind may result in a "hot wave," with maximum temperatures of over 90°.

If tropical air masses with associated south winds from regions that are usually warmer (Northern Hemisphere) import higher tempera-

tures to the regions toward which they blow, then polar air masses with associated north winds from colder, higher latitudes, or from the cold interiors of continents, should in turn bring lower temperatures. These importations are particularly effective where there are no mountain barriers to block the wind movement. In eastern North America where lowlands prevail, great masses of cold polar air periodically pour down over the Mississippi Valley, occasionally carrying severe frosts even to the Gulf States.

Not only the advection of air masses from different latitudes but also that of those moving from large water bodies onto lands bring contrasting temperatures in different seasons.

50. Radiation. Short-wave solar energy, absorbed at the earth's surface, is there transformed into heat. Through this absorption and conversion of insolation, the heated earth becomes a radiating body. But although the atmosphere is capable of absorbing only relatively small amounts (15 per cent) of short-wave incoming solar energy, it is, on the other hand, able to retain up to 90 per cent of the outgoing long-wave earth radiation. As stated before, water vapor is the principal absorbing gas. This absorptive effect of water vapor upon outgoing earth radiation is illustrated by the rapid night cooling in deserts, the dry air and clear sky permitting a more rapid escape of energy. Obviously the effect of the atmosphere is analogous to that of a pane of glass, which lets through most of the incoming short-wave solar energy but greatly retards the outgoing long-wave earth radiation, thus maintaining surface temperatures considerably higher than they otherwise would be. This is the so-called *greenhouse effect* of the earth's atmosphere.

Radiation of terrestrial energy from the earth's surface upward toward space is a continuous process. During the daylight hours up to about midafternoon, however, receipts of energy from the sun are in excess of the amount radiated from the earth, with the result that surface-air temperatures usually continue to rise until two to four o'clock in the afternoon. But during the night, when receipts of solar energy cease, a continued loss of energy through earth radiation results in a cooling of the earth's surface and a consequent drop in air temperature. Being a better radiator than air, the ground during the night becomes cooler than the air above it. When this condition prevails, the lower layers of atmosphere lose heat by radiation to the colder ground as well as upward toward space. This process is particularly effective during the long nights of winter when, if the skies are clear and the air is dry and calm, excessively rapid and long-continued radiation takes place. If a snow cover mantles the ground, cooling is even more pronounced, for not only is most of the incoming solar radiation during the short day reflected, but at night, the snow, which is a very poor conductor of heat, allows little to come up from the ground below to replenish that lost by radiation. As a result, the snow surface becomes excessively cold, and then in turn the air layer resting upon it.

Water, like land, is a good radiator, but the cooled surface waters keep constantly sinking to be replaced by warmer currents from below. Extremely low temperatures over water bodies are impossible, therefore, until they are frozen over, after which they act like a snow-covered land surface. Humid air or a cloudy sky tends to prevent rapid earth radiation so that air temperatures remain higher, and frosts are less likely on humid nights and especially when a cloud cover prevails. There are authentic cases, in the dry air and under the cloudless skies of Sahara, of day temperatures of 90° followed by night temperatures slightly below freezing. When clouds cover the sky, all the earth radiation is completely absorbed at the base of the cloud sheet, which in turn reradiates a part of it back to the earth so that cooling of the earth is retarded. Under a sky with low clouds the net loss of heat from the ground is only about one-seventh the loss with clear skies. Water vapor likewise absorbs and reradiates outgoing terrestrial energy but not so effectively as liquid or solid cloud particles.

Unlike heat transfer by conduction, convection, and advection, for which some sort of material medium is required, radiation is the only process by which heat can be transferred

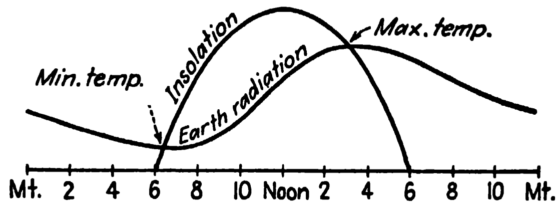


Fig. 19. Representation of incoming solar radiation and outgoing earth radiation for a period of 24 hr. at about the time of the equinox.

through space. It is the single means, therefore, by which heat can be gained from a source outside the earth, such as the sun, or by which the earth can ultimately lose its energy to space. Since the earth appears to maintain a relatively constant temperature, it must be that its receipts of solar radiation from the sun are balanced by the losses of earth radiation outward toward space.

51. Heating by Compression and Cooling by Expansion. When a mass of air descends from higher to lower altitudes, as, for instance, when it moves down a mountain slope, it is being transferred from regions of lower atmospheric pressure to those where it is higher. Because there is an increasingly thicker layer of air pressing down upon it as lower altitudes are attained, the descending mass of air gradually is being compressed in volume. Work is being done upon it, and as a result of compression its temperature is increased.

Just as descending air heats as a result of compression, so rising air cools as a result of expansion. In the latter case the upward current is traveling from a lower altitude where atmospheric pressure is greater to a higher altitude where pressure is less. As a consequence, the rising air continues to expand as the weight of atmosphere upon it becomes less. Work is done in pushing aside other air in order to make room for itself. This work done by the rising and expanding air consumes energy, which is subtracted from the ascending currents in the form of heat, resulting in a lowering of their temperature. Heating by compression and cooling by expansion do not involve heat transfer, for the temperature changes are the result of internal reactions within the descending or ascending air growing out of variations in altitude.

52. Heat Balance in the Atmosphere. Since the mean temperature of the earth remains about the same, getting neither colder nor warmer, it follows that the heat lost by the earth through radiation to space is identical with the amount of energy received from the sun. But although this balance is true for the earth as a whole, it is not true for individual latitudes. In the low latitudes, equatorward from about 37°, the incoming solar energy exceeds the outgoing earth energy, whereas poleward from latitude 37° exactly the reverse is true. Unless there is to be a constant increase in the temperatures of

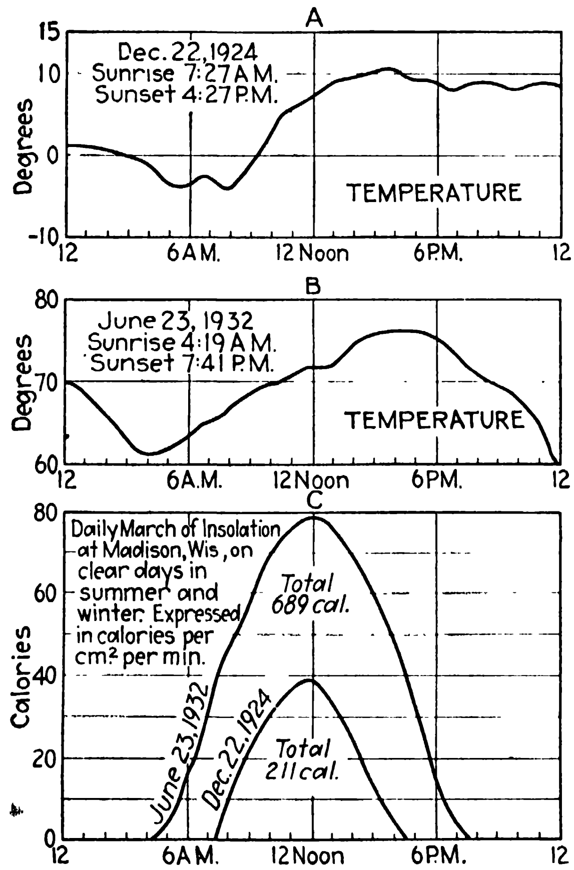


Fig. 20. Daily march of temperature (*A* and *B*) and of insolation (*C*) on clear days in winter and summer at Madison, Wis. The total solar energy received was 3¼ times as great on June 23 as on Dec. 22. Note that temperature lags behind insolation. South winds prevented normal night cooling on Dec. 22.

low latitudes and a constant decrease in the temperatures of the middle and higher latitudes, this situation requires a continuous transfer of energy from low to high latitudes of the earth. This transfer is accomplished by the winds of the earth. *In fact, in this unequal latitudinal distribution of solar and terrestrial radiation is to be found the ultimate cause for the earth's atmospheric circulation and for much of its weather.*

DAILY AND SEASONAL MARCH OF TEMPERATURE

53. All average temperatures for a month, season, year, or even a long period of years are built upon the *mean daily temperature* as the basic unit. The daily mean is the average of the highest and the lowest temperatures recorded during the 24-hr. period.

The mean daily march of temperature chiefly reflects the balance between incoming solar radiation and outgoing earth radiation (Fig. 19). From about sunrise until 2:00 to 4:00 P.M., when energy is being supplied by incoming solar radiation faster than it is being lost by earth radiation, the temperature curve usually continues to rise (Figs. 19 and 20). Conversely, from about 3:00 ± P.M. to sunrise, when loss by terrestrial radiation exceeds receipts of solar energy, the daily temperature curve usually falls.

The annual march, or cycle, of temperature reflects the daily increase in insolation (hence heat accumulated in the air and ground) from midwinter to midsummer and the decrease in the same from midsummer to midwinter (Fig. 21). Usually there is a temperature lag of 30 to 40 days after the periods of maximum or minimum insolation. This reflects the balance between incoming and outgoing energy.

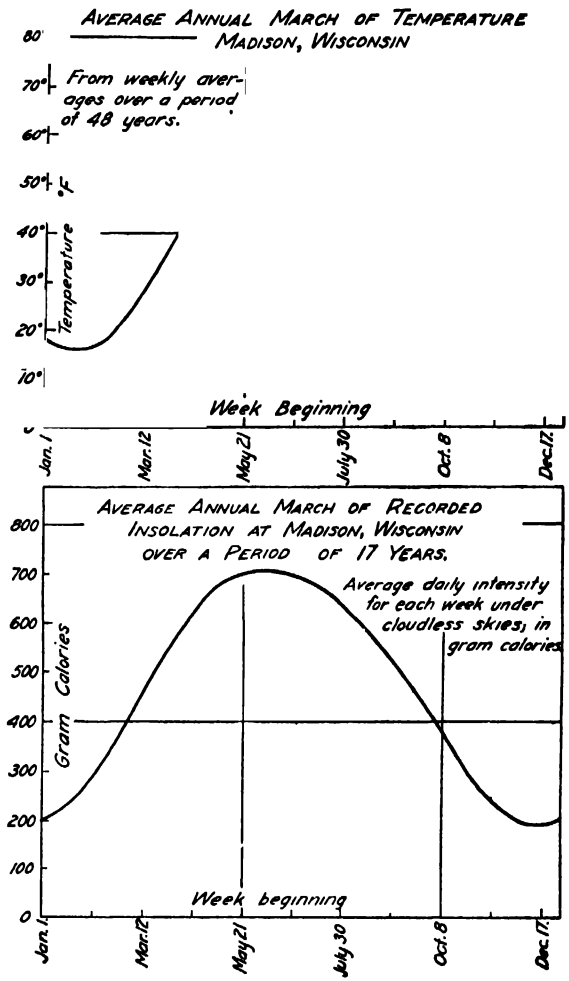


Fig. 21. Note that temperature lags behind insolation. Insolation curve has been smoothed slightly.

Distribution of Temperature: Vertical and Horizontal

VERTICAL DISTRIBUTION OF TEMPERATURE

54. Temperature Decreases with Altitude. Numerous temperature observations made during mountain, balloon, airplane, and kite ascents show that under normal conditions there is a general *decrease* in temperature with *increasing* elevation. Although the rate of decrease is not uniform, varying with time of day, season, and location, the average is approximately 3.3°F. for each 1,000-ft. rise (Fig. 22, *B*). The fact that air temperature is normally highest at low elevations next to the earth and decreases with altitude clearly indicates that most of the atmospheric heat is received directly from the earth's surface and only indirectly from the sun. But the lower air is warmer, not only because it is closest to the direct source of heat, but also because it is denser and contains more water vapor and dust, which cause it to be a more efficient absorber of terrestrial radiation than is the thinner, drier,

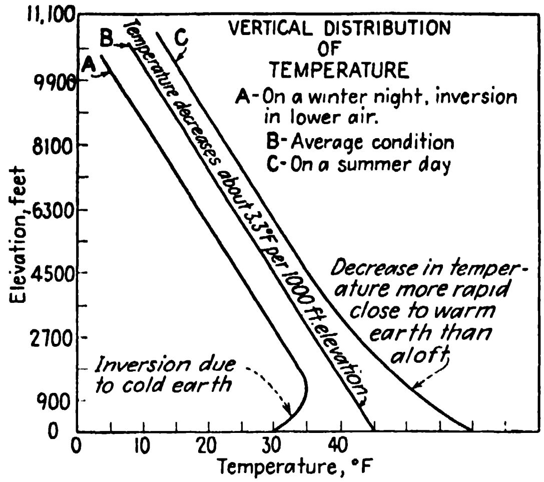


Fig. 22

cleaner air aloft. Two exceptions to this general rule of decreasing temperature with increasing altitude are (*a*) the stratosphere and (*b*) conditions of temperature inversion.

Above an elevation of approximately 10 miles at the equator, 6 miles in latitudes 45 to 50°, and 4 miles at the poles, the normal decrease in temperature halts and thermal conditions remain much more constant for another 12 miles or more. It is possible, then, to think of the earth's atmosphere as composed of two shells, or layers. The higher, or outer, shell, in which temperature conditions are fairly homogeneous, is known as the *stratosphere*. In it temperatures are very low, clouds are absent, dust and water vapor are at a minimum, convectional currents are lacking, and all air movement is horizontal. Below the stratosphere is the turbulent, dusty layer known as the *troposphere*, which contains much water vapor and also clouds and in which temperature decreases with increasing altitude.

55. Inversions of Temperature. Although the *normal* vertical temperature gradient (lapse rate) for the troposphere shows a decrease in temperature with altitude, it is not unusual (*a*) in middle and higher latitudes where losses from earth radiation exceed incoming solar radiation, especially (*b*) in the winter season when a snow cover may prevail, and (*c*) during the night hours, for the air closest to the ground to become colder than that some distance aloft. Under this arrangement, in which temperature *increases* with elevation, the normal situation is reversed or inverted and a *temperature inversion* is said to exist (Fig. 22, *A*).

The most intense, deep, and extensive inversions, and consequently those of greatest climatic significance, are produced by the advection of air masses. These may occur near to or far above the earth's surface. Such extensive inversions are of common occurrence over central United States in winter when cold polar continental air masses are thrust southward from the Arctic plains of Canada. Extensive inversions are common also in association with fronts where opposing unlike air masses meet.

Local, diurnal ground inversions of a few score or hundred feet in depth are well-known nighttime phenomena of the cooler seasons. They originate as a result of rapid chilling of a land surface through radiational cooling. Ideal conditions for these nocturnal radiation inversions are (*a*) long nights, as in winter, so that there will be a relatively long period when outgoing earth radiation exceeds incoming solar radiation; (*b*) a clear sky so that loss of heat by terrestrial radiation is rapid and unretarded; (*c*) cold dry air that absorbs little earth radiation; (*d*) calm air so that little mixing shall take place, and the surface stratum will, as a consequence, have time, by conduction and radiation, to become excessively cold; and (*e*) a snow-covered surface, which, owing to reflection of solar energy, heats little by day and, being a poor conductor, retards the upward flow of heat from the ground below. At the Eiffel Tower in Paris there is throughout the year an increase in temperature upward from base to top between midnight and 4:00 A.M. Strong surface inversions make the landing of an airplane difficult, for the added lift exerted by the dense cold air near the ground may make it difficult for the pilot to penetrate the inversion. A very close relationship exists between temperature inversions and frost phenomena, since conditions favorable for the one are also ideal for the other. Although temperature inversions are common on flattish land surfaces, they are, nevertheless, more perfectly developed in depressions.

millibars, and sea-level atmospheric pressure may be expressed as 29.92 inches, 760 millimeters, or 1,013.2 millibars.

Relation of Pressure in Inches to Pressure in Millibars

Inches	*Millibars*	*Inches*	*Millibars*	*Inches*	*Millibars*
27.00	914.3	29.00	982.1	29.92	1,013.2
28.00	948.2	29.50	999.0	30.00	1,015.9
28.50	965.1	29.75	1,007.5	30.25	1,024.4

But the density and weight of a given volume of air vary with temperature. Thus when air is heated it expands and becomes less dense, so that a column of warm, light air weighs less than a column of cold, heavy air, both having the same height and cross-sectional area. In central Asia in January, when air temperature is very low and its density therefore high, the air pressure is nearly 34 millibars, or 1 in. of mercury, greater than it is in summer. Changes in temperature produce changes in air density which set up vertical and horizontal movements resulting in changes in air pressure. Over a warm region air is heated, expands, and overflows aloft to adjacent regions where temperatures are lower (Fig. 28). As a result of this horizontal transfer the weight of the air is reduced in the warm region and increased in the adjacent cooler one. It may be accepted as a general rule, therefore, that regions with high temperatures are *likely* to have air pressures lower than those of other regions where temperatures are not so high. *In other words, high temperature tends to produce low pressure, and low temperature is conducive to high pressure.* But although the *ultimate* cause of pressure differences is probably regional contrasts in temperature, it is not to be inferred that the aforementioned direct relationship is always obvious. On the contrary, there are numerous apparent exceptions.

Distribution of Atmospheric Pressure

68. Vertical Distribution. Since air is very compressible it almost goes without saying that there is a rapid decrease in air weight or pressure with increasing altitude. The lower layers of the atmosphere are the densest because the weight of all the layers above rests upon them. For the first few thousand feet above sea level the rate of pressure decrease is in the neighborhood of 1 in., or 34 millibars, of pressure for each 900 to 1,000 ft. With higher altitudes the air rapidly becomes much thinner and lighter, so that at an elevation of 18,000 ft. one-half the atmosphere by weight is below the observer, although the whole air mass extends to a height of several hundred miles. The pressure is again halved in the next 18,000 ft., and so on. The human body is not physiologically adjusted to the low pressures and associated small oxygen content of the air at high altitudes, and nausea, faintness, and nosebleed often result from a too rapid ascent. Oxygen tanks are a part of the normal equipment of aircraft operating at high altitudes.

69. Horizontal Distribution. *Average Conditions.* Just as temperature distribution is represented by *isotherms,* so atmospheric pressure distribution is represented by *isobars, i.e.,* lines connecting places having the same pressure (Figs. 31 and 32). On the charts here shown, effects of elevation have been eliminated, all pressure readings having been reduced to sea level. Figure 29 is a very diagrammatic sketch of the arrangement of zonal sea-level pressure belts as they might exist on an earth composed of either all land or all water. This arrangement is recognizable in the seasonal isobaric charts for January and July (Figs. 31 and 32), particularly in the Southern Hemisphere where oceans predominate. North of the equator, where great land masses and oceans alternate, the zonal pressure b s are so disrupted that they are not always easily recognizable. The more or less ideal arrangement shown in Fig. 29 is likewise relatively obvious on a map of world pressure for spring or fall, months in which the disturbing

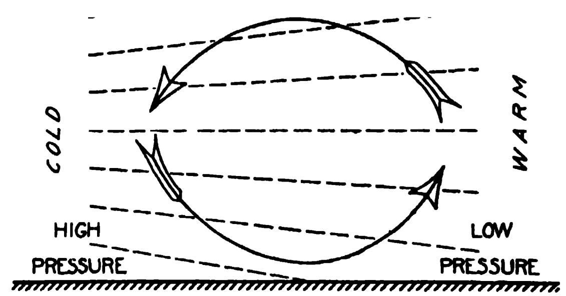


Fig. 28. The relationship of air temperature to pressure and winds. Dashed lines indicate surfaces of equal pressure.

effects of temperature contrasts between continents and oceans are least prominent.

According to the temperature-pressure rule stated in Art. 67, a nonrotating earth without land and water contrasts should develop a low-pressure belt at the equator with high-pressure centers at either pole. Owing in part to earth rotation this simple pressure arrangement does not prevail. Following are the most noteworthy and characteristic features of average world-pressure conditions at sea level on a rotating earth with a homogeneous surface (Fig. 29): (*a*) There is an *equatorial belt of low pressure* in the general vicinity, but slightly to the north, of the geographic equator. It coincides rather closely with the belt of highest temperature and is largely the result of those thermal conditions. As proof of this causal relationship it may be pointed out that the lowest pressures within the belt coincide with the highest temperatures, both being over the land areas. (*b*) A series of connected high-pressure centers form two irregular belts of high pressure at approximately 30 to 35°N. and S. These are known as the *subtropical highs*. (*c*) From the subtropical highs pressure decreases poleward toward the troughs of low pressure located roughly in the vicinity of the Arctic and Antarctic Circles. These are *subpolar troughs of low pressure*. In the Southern Hemisphere the trough is much deeper and more continuous and the pressure gradients are steeper than in the Northern Hemisphere. (*d*) Beyond the subpolar lows, pressure appears to rise with increasing latitude, resulting in the *polar highs*, for which there are few data. Like the low pressure at the equator, the surface high pressures in the polar regions are, for the most part, directly thermally induced.

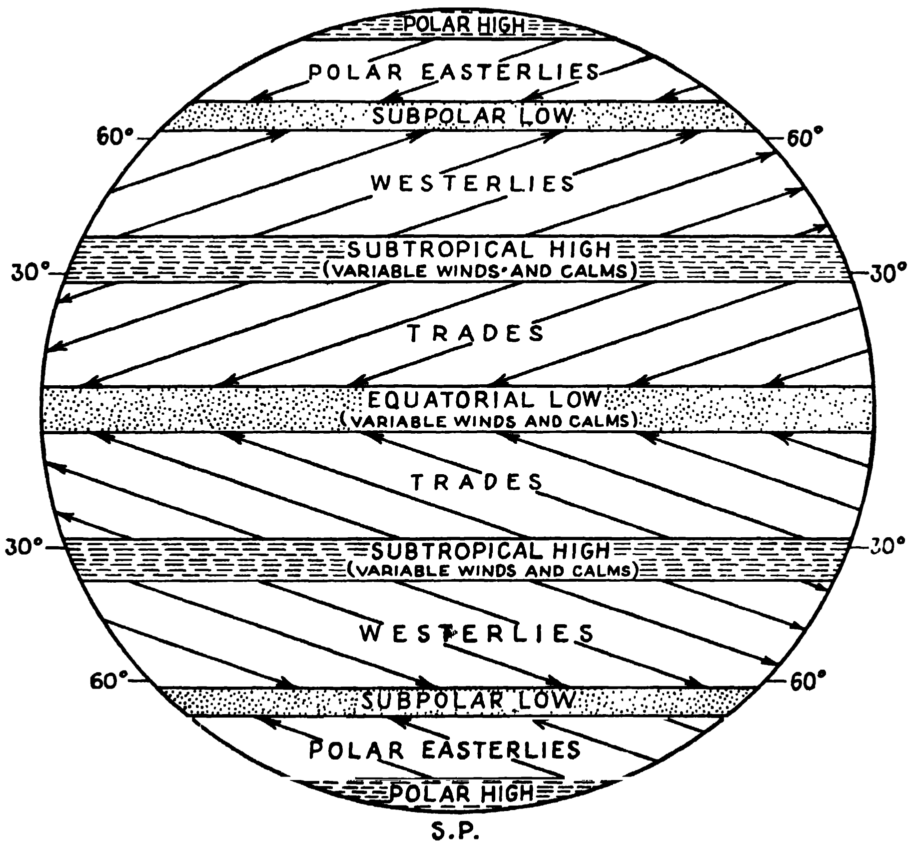


Fig. 29. A very diagrammatic representation of surface pressure and wind arrangements as they might appear on a rotating earth with a homogeneous surface.

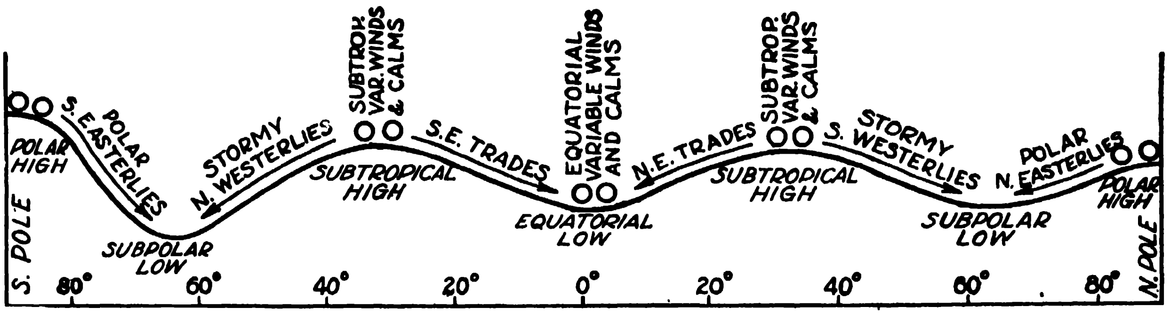


Fig. 30. A very diagrammatic representation of a profile of surface pressure and wind belts as they might appear on a rotating earth with a homogeneous surface. Compare with Fig. 29.

The character and arrangement of pressure features in the vicinity of the two poles are not entirely understood. In the Southern Hemisphere the symmetrical arrangement of land and water areas, with an elevated ice-covered continent at the pole and uninterrupted bordering ocean, appears to make for symmetrical pressure distribution as well. A permanent high over the Antarctic continent and a ring of low pressure surrounding it are the result. In the Northern Hemisphere, on the other hand, no such simple arrangement is evident.[1] At the North Pole is an ocean covered for most of the year by pack ice. Surrounding the Arctic Ocean are the land masses of Eurasia and North America with their great seasonal fluctuations of temperature and pressure, which in turn affect the inner polar area. During the cold seasons higher pressures exist over northern Eurasia and North America than at the pole. Ice-covered Greenland is more the center of a *permanent* Arctic high than is the immediate polar region. The Iceland and Aleutian lows over the North Atlantic and North Pacific Oceans, respectively (Fig. 32), are portions of the fragmented subpolar trough.

70. *Profile of Average Sea-level Pressure Distribution along a Meridian.* The general pressure features described above for a homogeneous earth are made clear in the very diagrammatic representation (Fig. 30) of a vertical section of pressure along a meridian from pole to pole. The line rises from the belt of low pressure near the equator to the subtropical highs at about 30 or 35°N. and S., then sinks until it reaches the subpolar lows in latitudes 60 to 70°, after which it rises again in the vicinity of the polar highs.

71. *Thermal and Dynamic Control of Average Sea-level Pressure Distribution.* Applying the general rule concerning the relationship between temperature and pressure (67) to Figs. 29 and 30 it is evident that only the equatorial low and the polar highs appear to conform. Certainly the subtropical highs are not in regions of excessive cold, nor are the subpolar lows in regions of unusual heat. These are major exceptions to direct thermal control of pressure. It may be suggested at this point that these two pressure features owe their existence and location to dynamic forces associated with earth rotation and the general atmospheric circulation, rather than to direct thermal influences, or to a compromise between the two.

72. *Isobars for January and July* (Figs. 31 and 32). The most noteworthy characteristics of pressure distribution in January and July, which represent the extreme seasons, are as follows: (*a*) Pressure "belts," like those of temperature, migrate north with the sun's rays in July and south in January, always lagging somewhat behind and usually not migrating so far as do the insolation belts. The latitudinal pressure migrations are greater over land masses than over the oceans, reflecting a similar situation with respect to temperature. (*b*) The subtropical high-pressure belts are broken or fragmented into definite and discontinuous centers by the warm continents in summer. In winter, on the other hand, the

[1] Excellent maps of Arctic pressures are contained in "Klima des Kanadischen Archipels und Grönlands," Vol. II, Part K of Handbuch der Klimatologie, edited by W. Köppen and R. Geiger. Gebrüder Borntraeger, Berlin, 1935.

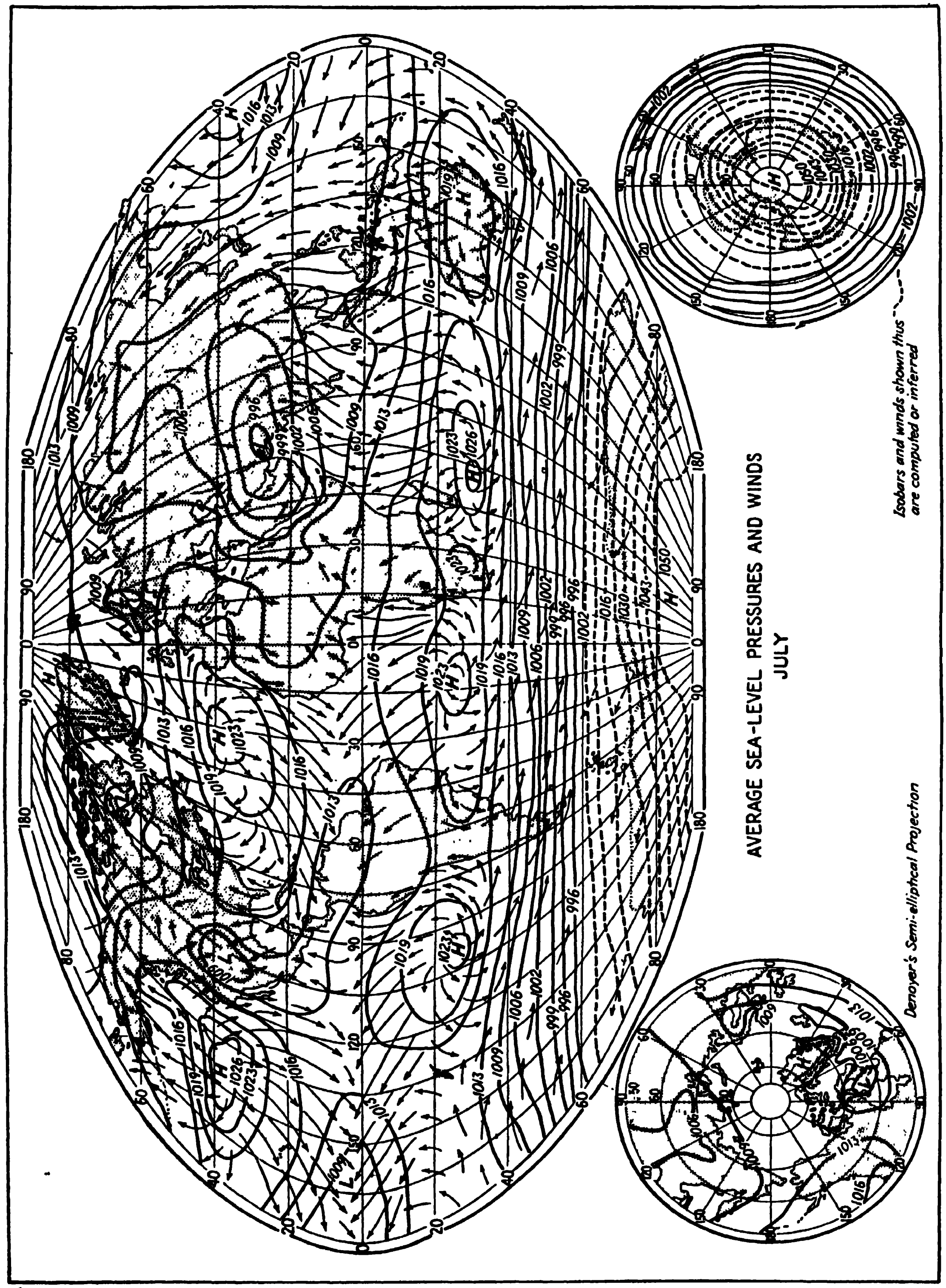

AVERAGE SEA-LEVEL PRESSURES AND WINDS
JULY
Denoyer's Semi-elliptical Projection
Isobars and winds shown thus are computed or inferred

Fig. 31

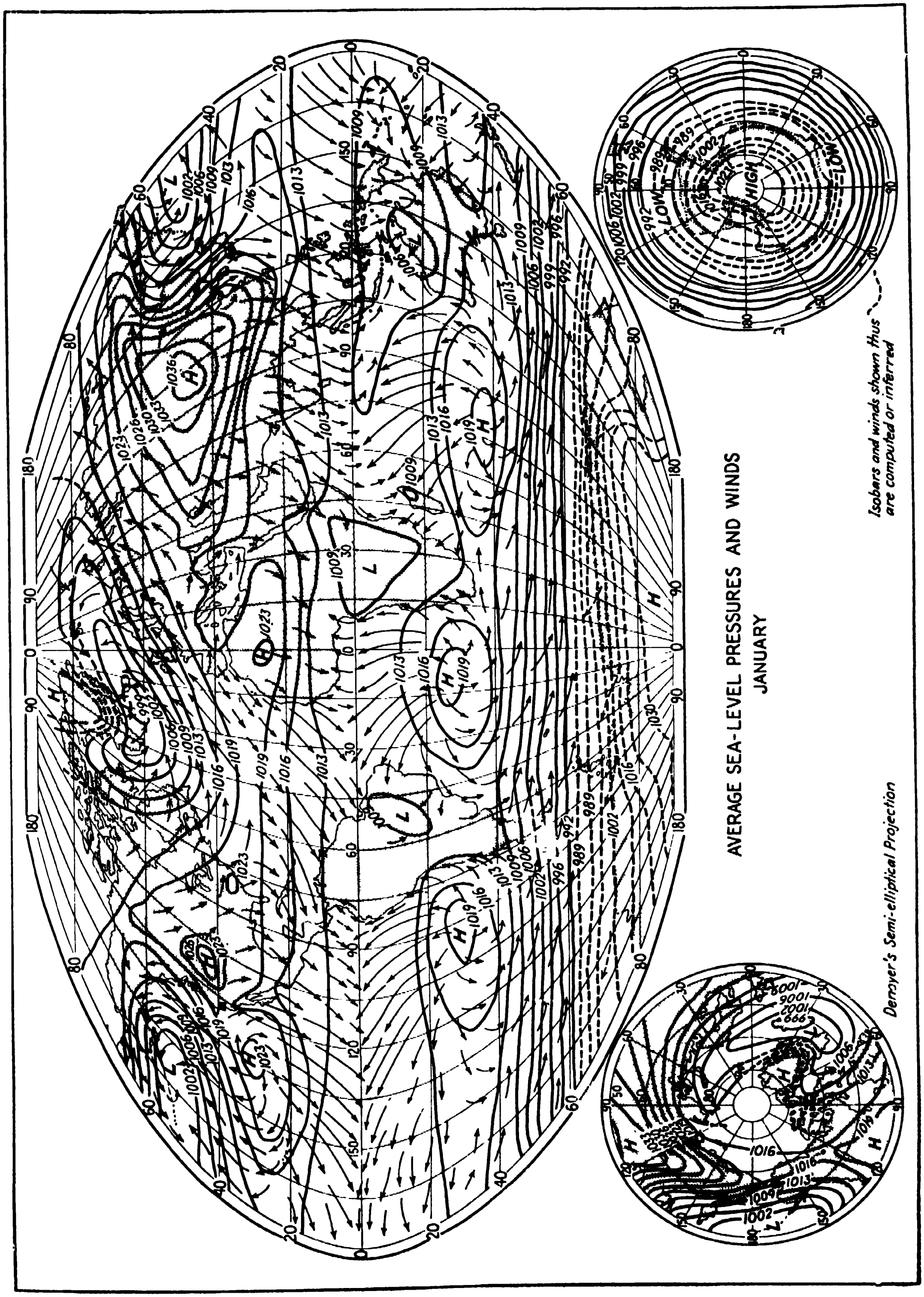

AVERAGE SEA-LEVEL PRESSURES AND WINDS
JANUARY
Isobars and winds shown thus are computed or inferred
Denoyer's Semi-elliptical Projection

Fig. 32

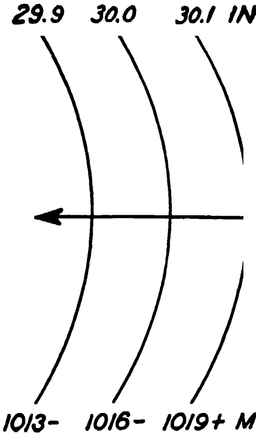


Fig. 33. Gradient is represented by a line drawn at right angles to the isobars.

cold land masses tend to strengthen the highs, making for greater continuity of the subtropical belts. (*c*) The middle-latitude continents, especially North America and Asia, become alternately sites of semipermanent high- and low-pressure centers in winter and summer, respectively. The adjacent oceans likewise reverse their seasonal pressure conditions, but they are low when the continents are high and vice versa. These seasonal reversals of pressure have their origins in the temperature contrasts between land and water in the opposite seasons (Figs. 25 and 26). In general, pressure is higher in the colder hemisphere where the air is denser. The extraordinarily large and deep continental low-pressure center developed over Asia in July tends to wipe out the equatorial low which would normally prevail to the south of that land mass. Both North America and Asia in winter develop such strong and extensive continental highs that the normal subtropical belts of high pressure are merged with them and are thereby shifted 10+° too far northward. Like the trough of low pressure at the equator, and the polar highs, the seasonal lows and highs over the large middle-latitude continents are of direct thermal origin. As indicated in an earlier article, because of the disrupting effects of seasonal temperature contrasts over the great continents and oceans of the Northern Hemisphere, seasonal *centers* of low and high pressure often are more conspicuous north of the equator than distinct pressure belts.

Relation of Winds to Pressure

73. Pressure Gradient. Air that moves essentially parallel to the earth's surface is referred to as wind. Vertical air movements are more properly designated as currents, although the name is often applied to horizontal movements as well. Wind is usually caused by differences in air density, resulting in horizontal differences in air pressure. It represents nature's attempt to correct pressure inequalities. The rate and direction of change of pressure, as indicated by isobaric lines, are referred to as *pressure gradient*, or *barometric slope*, and it is this which indicates the velocity and general direction of air movements. Two very fundamental rules concerned with the relationships existing between pressure and winds are as follows: (*a*) The *direction* of air flow is from regions of greater to those of less density, *i.e.*, from high to low pressure or down the barometric slope, which may be represented by a line drawn at right angles to the isobars (Fig. 33). This follows the law of gravitation and is just as natural as the well-known fact that water runs downhill. Because of the deflective force of earth rotation, however, the flow of air from high to low pressure is very indirect. (*b*) The *rate* of air flow, or velocity of the wind, is indicated by the steepness of the pressure gradient, or the rate of pressure change. When the gradient is steep, air flow is rapid, and when it is weak, the wind is likewise weak. Just as the velocity of a river is determined largely by the slope of the land, or rate of change in elevation, so the velocity of wind is determined largely by the barometric slope, or the rate of change in air pressure. One, therefore, can determine the steepness of the pressure gradient, and consequently the relative velocity of air movement, by noting the spacing or closeness of the isobars. Closely spaced isobars, like these in the vicinity of the subpolar trough in the Southern Hemisphere (Figs. 31 and 32), indicate relatively steep gradients, or marked pressure differences, and under these conditions winds of high velocity prevail. When isobars are far apart, gradients are weak, and winds are likewise. Calms prevail when pressure differences over extensive areas

are almost, or quite, nil. At such times there is nearly an absence of isobaric lines on the pressure map.

*Approximate Relation of Wind Velocity to Pressure Gradient near London, England**

Difference in Pressure per 15 Nautical Miles, Inches	*Corresponding Wind Velocity, Miles per Hour*
0.005	7.0
0.01	9.2
0.02	16.5
0.03	25.2

* W. G. Kendrew. "Climate." P. 73. Oxford University Press, New York, 1930. The nautical mile is 6,080 ft., or the length of 1′ of a great circle.

74. Wind Direction and Velocity. Winds are always named by the direction from which they come. Thus a wind from the south, blowing toward the north, is called a south wind. The wind vane points *toward* the source of the wind and so in a very general way toward the high-pressure area down the barometric slope of which the air is flowing. *Windward* refers to the direction from which a wind comes; *leeward*, that toward which it blows. Thus a windward coast is one along which the air is moving onshore, while a leeward coast has winds offshore. When a wind blows more frequently from one direction than from any other, it is called a *prevailing wind.*

Wind direction is referred to directions on a 32-point compass and is expressed in terms of letter abbreviations of the directions, by the

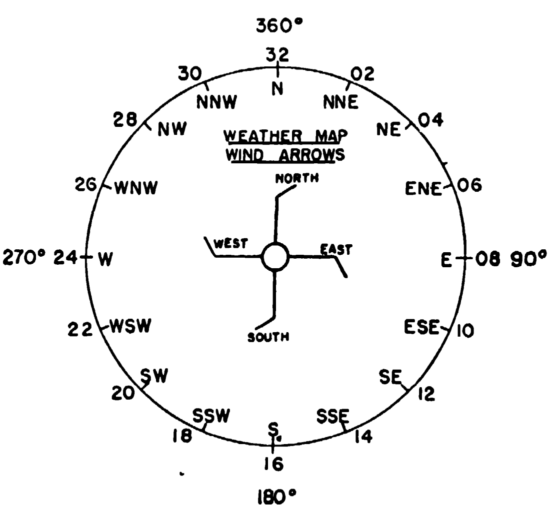


Fig. 34. Wind directions on a 32-point compass.

number of the compass point, or by the number of degrees east of north (Fig. 34).

The Beaufort Scale of Wind Force with Velocity Equivalents

Beaufort Number	*General Description*	*Specifications for Use on Land*	*Miles per Hour*
0	Calm	Smoke rises vertically	Less than 1
1	Light air	Wind direction shown by smoke drift but not by vanes	1 to 3
2	Slight breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind	4 to 7
3	Gentle breeze	Leaves and twigs in constant motion; wind extends light flag	8 to 12
4	Moderate breeze	Raises dust and loose paper; small branches are moved	13 to 18
5	Fresh breeze	Small trees in leaf begin to sway; crested wavelets form on inland water	19 to 24
6	Strong breeze	Large branches in motion; whistling heard in telegraph wires	25 to 31
7	Moderate gale	Whole trees in motion	32 to 38
8	Fresh gale	Twigs broken off trees; progress generally impeded	39 to 46
9	Strong gale	Slight structural damage occurs; chimney pots removed	47 to 54
10	Whole gale	Trees uprooted; considerable structural damage	55 to 63
11	Storm	Very rarely experienced; widespread damage	64 to 75
12	Hurricane	. . . .	Above 75

Wind velocity varies greatly with distance above the ground, and the variation is particularly rapid close to the ground. Wind is not a steady current but is made up of a succession of gusts and lulls of variable direction. Close to the earth the gustiness is caused by the irregularities of the surface which create eddies. Larger irregularities in the wind are caused by convectional

currents. All forms of turbulence of the wind are important in the process of transporting heat, moisture, and dust into the upper air.

The Earth's Wind Systems

THE PLANETARY SYSTEM OF WINDS

75. A Hypothetical Thermally Controlled Atmospheric Circulation. The earth's wind systems are complicated. For that reason it is deemed advisable to approach their study by an analysis that proceeds from the simple to the complex and in which the several complications are added one at a time.

First, let there be assumed a *nonrotating* planet having a *homogeneous level surface* (composed of either all land or all water) and with the maximum solar energy at the equator and a minimum at the poles (Fig. 35). On such a homogeneous nonrotating planet, temperatures would diminish regularly from equator to poles. Atmospheric pressure, under thermal control, would then be highest at the poles, diminishing toward a permanent trough of low pressure at the equator. The heated air in the low latitudes would expand, rise, and overflow aloft, moving out toward the poles in the higher altitudes. In the polar regions it would sink to the earth, feeding the cool surface currents that would flow

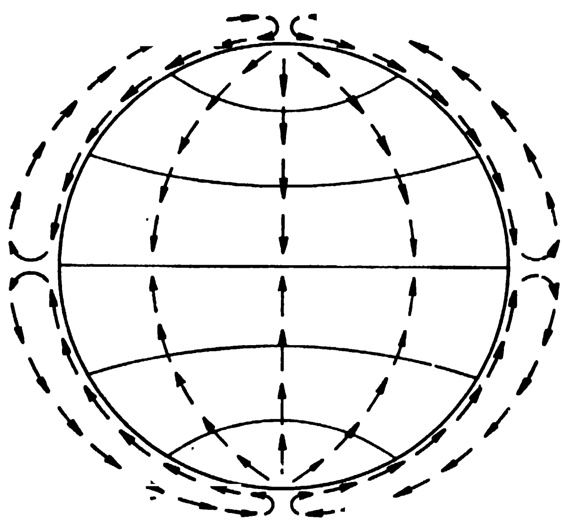


Fig. 35. System of winds as it might develop on a homogeneous nonrotating earth with the maximum solar energy received at the equator.

from the higher latitudes toward the equator. Under this situation it is obvious there would be two gigantic convectional circulations, one in each hemisphere, between the warm equatorial and the cold polar regions. That such a simple thermally induced air circulation does not exist is largely the result of (*a*) the earth's rotation on its axis and (*b*) the disrupting effects of land and water surfaces.

76. Diagrammatic Representation of Surface Winds on a Rotating Earth with a Homogeneous Surface. A closer approach to a correct representation of actual wind circulation, because it takes into consideration the effects of a rotating earth, is set forth in Figs. 29 and 30. A homogeneous surface is still assumed, however. Two fundamental differences are at once observable: (*a*) the rotating earth develops zones of high surface pressure in the subtropics at about latitude 30 to 35°, and conditions of low pressure at about latitude 60 to 65°, which result in several different belts of winds between equator and poles; and (*b*) the deflective force of earth rotation causes winds to deviate from a north-south gradient direction.

If rain were to fall upon a land surface the configuration of which is represented by the very much idealized profile of pressure along a meridian (Fig. 30), it is fairly obvious that six distinct and separate streams of water would result. Each would originate at one of the four higher elevations and flow downslope to one of the three intervening depressions. In a similar way six great surface air movements, or winds, corresponding to the six streams of water, result from the idealized pressure distribution from pole to pole on a homogeneous earth represented in Fig. 30. Each stream of air originates in an area of high pressure and, acted upon by gravity, flows down the barometric slope toward an area of low pressure. Two of the great air streams originate on the equatorial sides of the subtropical high-pressure centers and, controlled by the gradient, move toward low pressure near the equator. These are the *trades*. Two others originate on the poleward sides of the subtropical highs and move poleward toward the subpolar troughs of low pressure.

These are the *stormy westerlies*. Still another pair originates at the polar highs and flows equatorward toward the subpolar lows, where they meet the stormy westerlies from the lower latitudes. These high-latitude winds, about which relatively little is known, are sometimes designated as the *polar easterlies*. Both at the bottoms of the low-pressure troughs and at the crests of the high-pressure ridges, where pressure gradients are weak and variable, the wind systems are poorly developed, and calms and variable winds are characteristic. Thus between the trades, and at the bottom of the equatorial low-pressure trough, is the *equatorial belt of variable winds and calms*, or *doldrums*. At the tops of the subtropical highs, between the westerlies and the trades of either hemisphere, are the *subtropical belts of variable winds and calms*, sometimes called the *horse latitudes*. Still other regions having variable winds, but little calm, are to be found in the subpolar troughs of low pressure between the stormy westerlies and the polar easterlies. These regions of storm and variable winds have no general and accepted name.

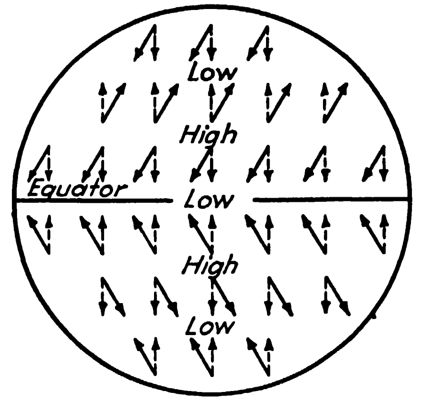


Fig. 36. Dashed arrows show wind direction as developed by the pressure gradient. Solid arrows indicate deflected winds resulting from earth rotation.

77. Deflection of Winds Due to Earth Rotation. If the earth's surface-air currents described above are represented on a map instead of on a profile, they may be shown very diagrammatically as in Fig. 29. It is immediately obvious that the surface winds do not, as might be expected, flow directly down the barometric slope (right angles to the isobars) but instead are always deflected into oblique courses. Thus the trades instead of flowing from north or south along the meridians are from the northeast and southeast. Similarly, the winds on the poleward sides of the subtropical highs (stormy westerlies) do not flow north or south but are southwesterlies and northwesterlies, while those originating at the polar highs are northeasterlies and southeasterlies. The cause for this bending of winds from the true gradient direction is the deflective force of the earth's rotation. This deflective force causes all winds in the Northern Hemisphere to be turned to the *right* and those of the Southern Hemisphere to the *left*. This will not be apparent from looking at the winds on Fig. 36 unless it is kept in mind that one must face in the direction toward which the wind is traveling in order to appreciate the proper deflection. Only at the equator is the deflective force of earth rotation absent, and it increases with increasing latitude. At 3,000 to 4,000 feet above the earth's surface where friction is greatly reduced, deflective force causes the winds to blow nearly parallel to the isobars. The surface winds over the lands usually make an angle of 20 to 40° with the isobars, and it may be as low as 10° over the oceans. At several thousand feet above the earth's surface, where the winds closely parallel the isobars, the direction of air movement is such that the lowest pressure is on the left (Northern Hemisphere).

78. Circulation on a Nonhomogeneous Earth. Admittedly the scheme of pressure and winds on a homogeneous rotating earth, represented by Figs. 29 and 30, is so much simplified that it does not accurately represent the true condition of surface winds. Nevertheless, it does provide a valuable *idealized framework* on which to hang the numerous modifications to be dealt with later. Chief of these modifications is the result of the fact that the earth is not homogeneous but is composed of land and water areas that have a disrupting effect upon any truly zonal circulation. Such a zonal circulation of winds as that represented by Figs. 29 and 30 is best exemplified in the Southern Hemisphere with its more nearly uniform water cover. In the Northern Hemisphere with its great continents and oceans the belts of low and high pres-

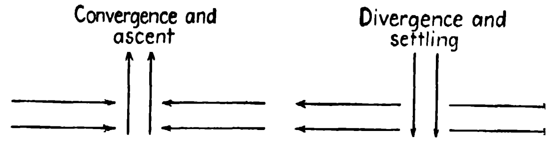


Fig. 37. Ascending currents resulting from convergence and descending currents resulting from divergence.

sure are broken down into isolated centers with distinct cyclonic and anticyclonic atmospheric circulations about them. During the winter at least six such distinct quasi-permanent centers may be observed: the Icelandic low, the Aleutian low, the Pacific high, the Bermuda or Azores high, the North American high, and the Asiatic high (see Figs. 31 and 32).

General Circulation of the Atmosphere

79. Necessity for a General Circulation. In the chapter on temperature it was pointed out that there is an excess of incoming solar radiation over outgoing earth radiation in the lower latitudes, while exactly the opposite is true in the higher latitudes, and still there is no progressive change in the climates of the various latitudes. To maintain this equilibrium there is required a transfer, by some means, of the heat from the general region of excess in the lower latitudes to the region of deficiency in the middle and higher latitudes. This necessary transfer is brought about largely through the circulation of the atmosphere and to a less degree by the circulation of the ocean waters.

Although in earlier editions of this book an attempt was made to outline the principal elements of a general circulation of the atmosphere, including that of the upper air, a treatment of the topic is omitted from this latest edition. The reason for this omission is an increasing realization of the inadequacy of the explanations now available. The large-scale air motions of the atmosphere, together with the processes that produce them, have come to be recognized as so extremely complex that no adequate theory of the general circulation of the atmosphere can be said to exist. The problems associated with general atmospheric circulation represent one of the most active frontiers of meteorological research at the present time. Under the existing conditions it seems wiser to omit any attempt at description and explanation of the circulation of the upper air and to confine the treatment to a description of the surface winds.

80. Zones of Convergence and Divergence. From the preceding analysis of the zonal system of surface winds on a rotating earth (Figs. 31 and 32) it becomes clear that there are on the earth certain general latitudes where the great planetary surface winds *converge* and clash, and there are others where they *diverge* and separate. Facts concerning the location and nature of the zones or belts of atmospheric convergence and divergence are of utmost importance in world weather and climate. Where there is a convergence of air masses, there must of necessity be an escape of that air through upward movement (*ascendance*), a condition which favors the development of storms, with associated cloud and precipitation. By contrast, where winds move away from a common source, or diverge, it is required that there shall be a downward movement of air from aloft (*subsidence*) in order to compensate for the divergent surface flow. Such a subsidence of the air is opposed to cloud, rain, and the formation of storms (Fig. 37).

81. *Zones of Convergence and Ascendance.* Three general zones or belts of widespread convergence and ascendance of air are to be noted. These are coincident with the zonal belts of low pressure. One of these is in the low latitudes close to the equator where the northeast and southeast trades converge, and the heavy precipitation and the general storminess in the vicinity of the equator are the result of this convergence. The equatorial convergence is sometimes spoken of as the *intertropical front*. On a nonrotating earth heated at the equator the equatorial convergence would be the only one present. As a result of earth rotation, however, there are developed the subtropical highs and the subpolar lows with poleward flowing westerlies prevailing in the middle latitudes. These winds, since they flow from warmer to colder regions, are opposite in direction to those of a thermally induced convectional circulation as represented by the trades on one side and the polar easterlies on the other. Because of the pole-

ward moving westerlies of the middle latitudes there result two additional zones of atmospheric convergence in the higher middle latitudes, one in the Northern Hemisphere and the other in the Southern. Here in the vicinity of the subpolar lows the westerlies clash with the equatorward surging polar winds, resulting in changeable weather, storms, and precipitation.

82. *Zones of Divergence and Subsidence.* As indicated above, where divergence of surface winds is the rule, it follows that there must be a settling or subsidence of air from higher altitudes in order to feed the outward flowing surface currents. This downward type of vertical air movement, called subsidence, has a warming and drying effect upon the air involved and is completely opposed to the formation of storms with associated cloud and precipitation. Regions of subsidence, therefore, are characterized by fair weather and little rain. The subtropical high-pressure belts, one in either hemisphere, are the earth's principal zones of diverging winds and associated subsidence. Here too are some of the great deserts of the world. The high-pressure centers, in the general vicinity of the poles, are likewise areas of settling and divergence.

The Surface Winds and Their Characteristics

83. Wind Belts, Centers of Action, and Air Masses. In order to state the case simply and with the fewest complications, the brief description of surface winds that follows is organized around the well-known planetary system. These are the conditions as they would prevail on a homogeneous earth, *e.g.*, one whose surface was all water. In a general way zonal wind belts do exist, but on the other hand such a concept obviously greatly simplifies what in reality is a very complicated atmospheric circulation. In the relatively homogeneous Southern Hemisphere, the belted arrangement of winds is conspicuous. In the Northern Hemisphere with its great continents and oceans, the average wind conditions for January and July (Figs. 31 and 32) show monsoonal circulations of air around distinct pressure centers. They are like the gear wheels of a great machine. However, since these centers of spiraling circulations are disposed longitudinally, the zonal arrangement of winds is still fairly conspicuous, especially over the oceans. It needs to be emphasized, however, that both wind belts and wind spirals as they appear on annual or seasonal charts are simply averages of what, on the daily weather maps, are seen to be great irregularly moving masses of homogeneous air, associated with traveling high- and low-pressure centers. It is this modern concept of the atmosphere, as composed of nonperiodic moving air masses, making contact with each other along fluctuating margins or fronts, that comes closest to reality.

84. The Doldrums, or Equatorial Belt of Variable Winds and Calms. As the northeast and southeast trades converge toward the equator, the fact of convergence forces the air to rise, leaving between the trades at low elevations a stagnant air condition of light and baffling breezes with much calm (Fig. 38). This doldrum belt therefore occupies the axis or valley of lowest pressure in the equatorial low-pressure trough where pressure gradients are weak and variable, resulting in winds of the same character. It needs to be emphasized that the nature of the winds is the result of the character of the barometric gradients. The belt of calms and variable winds is not clearly marked all around the equator, nor does it exist at all times of the year. In places and upon occasions it may be reduced to the vanishing point by the encroaching trades or by monsoons, and then again it may expand to twice its normal width. Its northern and southern margins may fluctuate several degrees even within the period of a few days.

As a result both of convergence and of thermal convection the principal air movement is vertical rather than horizontal, ascending currents being indicated by the abundance of cumulus clouds, numerous thunderstorms, and heavy convectional rainfall. Because this is a region of converging air currents which escape by upward movement, the doldrums are inclined to be turbulent and stormy, with calms, squalls, and light winds alternating. Within the doldrums calms prevail 15 to 30 per cent of the time, and winds, chiefly light and gentle breezes, come from all points of the compass with about equal

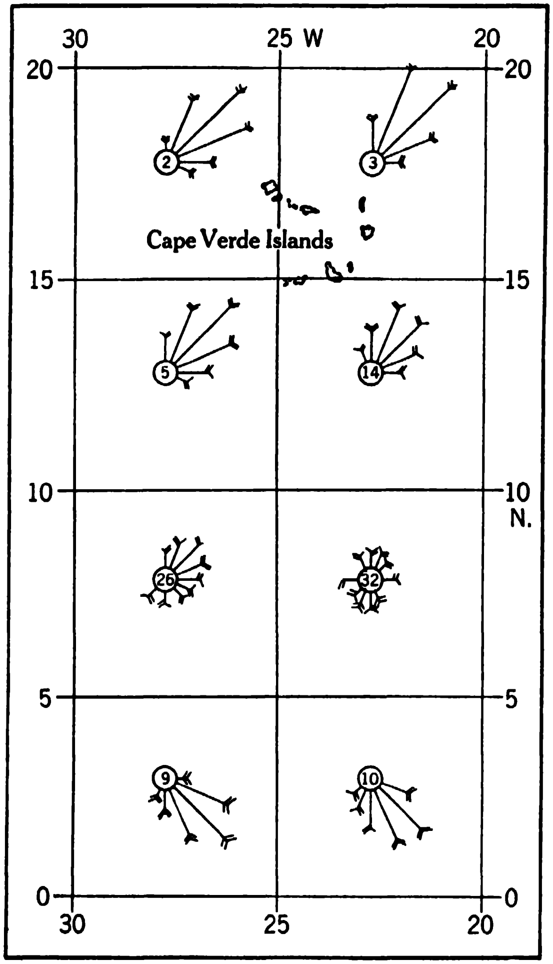


Fig. 38. Northeast and southeast trades and doldrums over the Atlantic Ocean in June. The wind rose is given for each 5° square. Arrows fly with the wind. The length of the arrow is proportional to the frequency of winds from that direction. The number of feathers on the arrow indicates the average force of the wind on the Beaufort scale. The figure in the center gives the percentage of calms, light airs, and variable winds. (*U.S. Hydrographic Office Pilot Chart.*)

frequency (Fig. 38). Poor ventilation and sultry, oppressive weather are characteristic. These regions were rigorously avoided by sailing vessels. Owing to the fact that a sailing ship could very well be becalmed for days in the doldrums because of lack of wind, such boats often took longer routes and went far out of their courses in order to cross in the narrowest parts of the belt. Although the doldrums are usually spoken of as a belt, it would be incorrect to conceive of this condition of variable winds and calms as having definite northern and southern boundaries. Irregular in width but averaging perhaps 200 to 300 miles, it extends in places for as much as 10° or more away from the equator, whereas in other longitudes, especially where monsoons are well developed, as they are in the Indian Ocean, it may be wiped out entirely. Over the Atlantic Ocean in July doldrums lie between latitudes 11 and 3°N. and in January between 3°N. and 0°. Most of the doldrum belt probably lies between parallels 5°N. and 5°S. In modern air-mass terminology the humid, sultry air of this doldrum region is designated as tropical unstable or equatorial (*E*). No other of the earth's air masses is both so warm and so humid and none, therefore, has equal potentialities for yielding heavy precipitation.

85. Intertropical Front. Although typical doldrum conditions, involving stagnant equatorial air masses associated with much vertical ascent, may be the prevailing condition in equatorial latitudes, there are sections, especially over the oceans, where the two trades converge into a sharply defined frontal zone with no belt of stagnant air between. This line of convergence has been called the *intertropical front.* The intertropical front (I.T.F.) is best developed in the eastern parts of equatorial oceans, and more especially at those seasons when the zone of convergence is farthest away from the equator. At such times there are the greatest contrasts in vertical temperature, moisture, and velocity between the two trade-wind air masses, although, to be sure, they are relatively small at all times. When the I.T.F. is very close to the equator, the two trades are so identical in density that no true front is formed, and the I.T.F. is only a zone of convergence (*intertropical convergence,* I.T.C.) along which there is strong vertical movement and associated outflow aloft.

When the I.T.F. has shifted farther away from the equator, the trade from the winter hemisphere is forced to cross the equator, after which, as a result of deflection, this recurved trade becomes a westerly current. Under these conditions the angle at which the two trades converge is nearly 180°, and the contrasts in their densities

is greater, so that the convergence is strong and a true front may be formed. Here the slightly warmer or more humid trade will be forced to ascend over the denser or more aggressive one along a mildly sloping discontinuity surface. The weather along the I.T.F. depends to a large extent upon the amount of convergence and the contrasts in the density of the two trades. Along with the abundance of cumulus cloud and thunderstorms there is often the development of cyclonic waves. These latter storms are associated with a heavy unbroken cloud deck and long-continued rain, features which are not so common in the stagnant air of the doldrums proper.

86. The Trade Winds. Moving obliquely downgradient from the subtropical centers of high pressure toward the equatorial low, roughly between latitudes 30 or 35° and 5 or 10° in each hemisphere over the oceans, are winds whose steadiness has earned for them the name *trade winds*. Over the North Atlantic in summer the approximate limits of the northeast trades are 35 and 11°N., in winter, 26 and 3°N. In parts of the low latitudes they reach, and even cross, the equator. Away from land masses trades blow rather constantly from an easterly direction (northeast in the Northern and southeast in the Southern Hemisphere). Over continents, and even adjacent to them, both steadiness and direction may be considerably modified. On the island of St. Helena, which lies in the heart of the southeast trades of the South Atlantic, the percentage of winds from various directions is as follows, according to Kendrew:[1]

	N.	*N.E.*	*E.*	*S.E.*	*S.*	*S.W.*	*Calm*
January	..	..	5	76	19		
July	1	2	9	62	20	1	5

They are the most regular and steady winds of the earth, particularly over the oceans, their characteristic moderate to fresh breezes averaging 10 to 15 miles an hour. Calms are infrequent, usually prevailing less than 5 per cent of the time (Fig. 38). Over land masses and near their margins, the surface trades are much less conspicuous. They blow with greater strength and constancy in winter than in summer, for in the hot season the belt of subtropical highs is broken by the heated continents, resulting in a much less continuous belt of trades at that season. Especially over eastern and southern Asia, and to a degree over the waters south and east of the United States as well, summer monsoons tend to weaken or even eliminate the trades. In winter, on the other hand, outflowing continental winds tend to strengthen the trades. In general, except on their equatorward margins, they are regions of fine, clear weather with few storms. The most spectacular of these storms are the tropical hurricanes which infest their western poleward margins over the oceans in the late summer and early fall. The poleward portions of the trades lying on the flanks of the subtropical highs where there is a good deal of subsiding air are relatively dry, and fair weather is prevalent. Farther equatorward and closer to the equatorial zone of convergence where ascent of air rather than subsidence is characteristic, the trades become increasingly rainier.

[1] Kendrew. *Op. cit.* P. 90

Because of the steady nature of the trades, as well as their fine clear weather with few severe storms, they were thoroughfares for sailing vessels. Columbus on his first voyage to the New World sailed south from Spain to the Canary Islands and then westward in the trades. His journal of the voyage contains frequent remarks concerning the fine weather and the favorable winds experienced. One notation describes the weather as being like April in Andalusia. The almost constant following winds from the northeast worried the sailors, however, for they feared that the return trip to Spain might be impossible. Upon one occasion when a westerly wind was experienced, Columbus wrote: "This contrary wind was very necessary to me, because my people were much excited at the thought that in these seas no wind ever blew in the direction of Spain."

87. The Subtropical Belts of Variable Winds and Calms, or the Horse Latitudes. Lying between the diverging trades and stormy westerlies over the oceans and occupying the crests of the high-pressure centers where pressure gradients are weak are areas of light, variable

winds and calms (Fig. 39). All regions with such wind characteristics must of necessity have weak pressure gradients. Perhaps the horse latitudes are better thought of as transition conditions between trades and westerlies rather than as relatively distinct and more or less continuous wind belts. On the wind charts (Figs. 31 and 32) the horse latitudes are the centers of the great subtropical "whirls" of air, these whirls having opposite rotations in the Northern and Southern Hemispheres. Although the horse latitudes are like the doldrums in their preponderance of light and fickle winds, blowing from any and all points of the compass, they are totally unlike them in their general weather conditions. Because they are regions of settling air and diverging wind systems (compare with doldrums), the air is prevailingly dry, skies are clear, weather is fine much of the time, sunshine is abundant, and rainfall is relatively low. As a general rule the western and equatorial margins of the subtropical whirls, where subsidence is less marked and the air has traveled a longer distance over tropical seas, have much more cloud and rainfall than the eastern sides. The centers, or "ridges," of subtropical high pressure lie in the vicinity of latitudes 30 to 40°N. and S. These are sometimes known as the Mediterranean latitudes because they correspond in location with that sea. The representative wind rose (Fig. 39) for these regions resembles that of the doldrums, calms prevailing 15 to 25 per cent of the time, and light and gentle breezes from all points of the compass the remainder.

88. The Stormy Westerlies. Moving downgradient from the centers of subtropical high pressure to the subpolar lows (roughly 35 or 40 to 60 or 65°) are the stormy westerlies. Particularly is the poleward boundary of this wind belt a fluctuating one, shifting with the seasons and over shorter periods of time as well. The westerlies are distinctive among the wind belts in that they are not uniformly either strong or weak but instead are composed of extremes. Spells of weather are one of their distinguishing characteristics. At times, and more especially in the winter, they blow with gale force, and upon other occasions mild breezes prevail. Although designated as *westerlies*, westerly being, to be sure, the direction of most frequent and strongest winds, air does blow from all points of the compass (Fig. 40). The variability of winds, in both direction and strength, so characteristic of the westerlies, is largely the result of the procession of storms (cyclones and anticyclones) which travels from west to east in these latitudes. These storms, with their local systems of converging and diverging winds, tend to break up and modify the general westerly air currents. Moreover, on the eastern sides of Asia, and to a lesser degree North America, continental wind systems called *monsoons* tend to disturb the westerlies, especially in summer (93). It is in the Southern Hemisphere, where in latitudes 40 to 65° land masses are largely absent, that the stormy westerlies can be observed in their least interrupted latitudinal development. Over these great expanses of ocean, winds of gale strength are common in

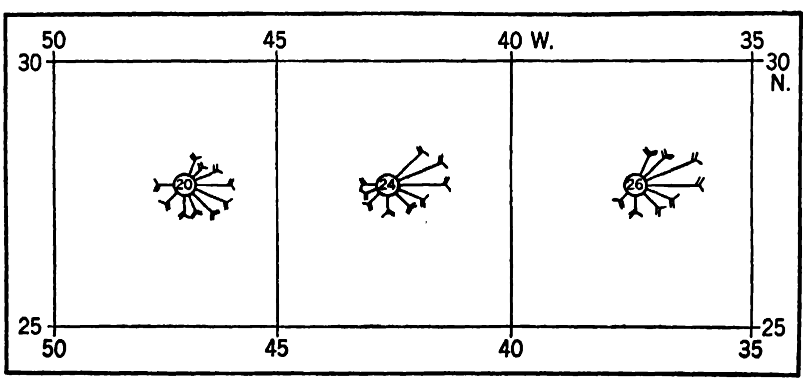


Fig. 39. The subtropical "belt" of variable winds and calms, or horse latitudes, over the North Atlantic Ocean in June. For explanation of symbols see Fig. 38. (*U.S. Hydrographic Office Pilot Chart.*)

summer as well as winter. These are the roaring forties of nautical jargon. In the vicinity of Cape Horn they are often so violent as to make east-west traffic around the Cape not only difficult but even dangerous. It is a wild region where gale follows gale with only brief intervening lulls, where raw chilly weather, cloudy skies, and mountainous seas prevail.

The westerlies of the Northern Hemisphere, where the great land masses with their seasonal pressure reversals cause the wind systems to be much more complex, are considerably less violent in summer than in winter. In the former season gentle to fresh breezes prevail, and winds come from a great variety of directions with almost equal frequency. But in winter they are like their counterparts in the Southern Hemisphere, being strong and boisterous with a greater prevalence of winds from westerly directions. The poleward margins of the westerlies near the subpolar troughs of low pressure are particularly subject to great surges of cold polar air in the winter season. The sinuous line of discontinuity, known as the polar front, which separates the cold, dry polar air from that warmer and more humid mass coming from the subtropics in the form of the westerlies is the zone of origin for a great many middle-latitude cyclones and anticyclones. It follows, therefore, that the poleward margins of the westerlies are much more subject to stormy, variable weather than are the subtropical margins. Since this polar front and the accompanying belt of storms migrate with the sun's rays, retreating poleward in summer and advancing equatorward in winter, it also follows that storm control of weather in the middle latitudes should be much more pronounced in the winter season.

89. The Polar Winds. In the higher latitudes, beyond the belts of westerlies, meagerness of long-continued observations prevents one from speaking with great assurance regarding the wind systems. The subpolar low-pressure troughs, relatively continuous in the Southern Hemisphere but existing as isolated centers (Iceland low and Aleutian low) north of the equator, are extremely wild and stormy areas, for they are the routes followed by a large num-

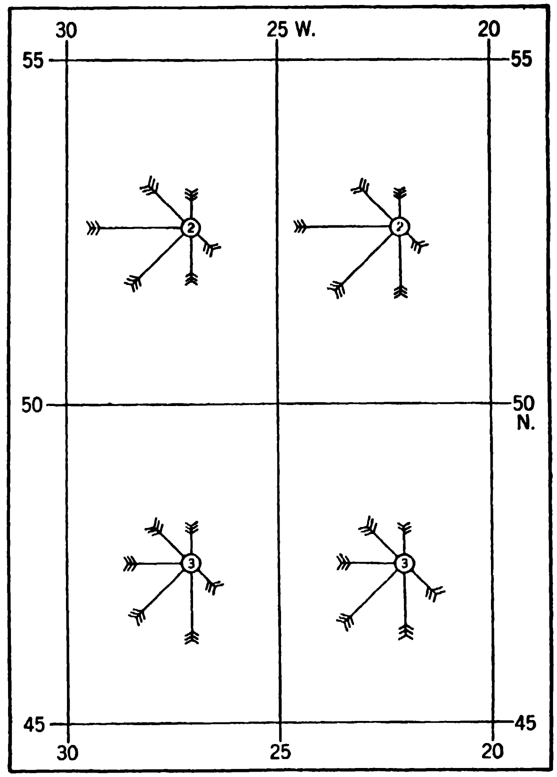


Fig. 40. The westerlies over the North Atlantic Ocean in January. For explanation of symbols see Fig. 38. (*U.S. Hydrographic Office Pilot Chart.*)

ber of the cyclonic storms of high latitudes. Great surges of cold polar air cause the outlines of the subpolar troughs to be extremely sinuous, almost completely interrupting their continuity both frequently and at numerous points. The inner polar areas of settling air and high pressure are probably quiet, relatively calm, and free from storms. The outflowing easterlies are, for the most part, moderate in velocity, although at times they are intensified to the point of becoming violent gales, blizzardlike in character. However, these blizzards appear to be more characteristic of the outer margins of the polar highs than they are of the inner, anticyclonic polar regions. As indicated previously, the surface wind system of the north polar region is much more complicated and complex than that of the Antarctic, owing to the proximity of great land masses near to, but not at, the Pole and to the asymmetrical position of the Greenland Ice

Cap. The permanent high pressure over Greenland is, for the year as a whole, the wind pole of the Northern Hemisphere, as the Antarctic high is for the Southern Hemisphere.

TERRESTRIAL MODIFICATIONS OF THE PLANETARY WIND SYSTEM

90. Thus far many of the general features of the wind system described have been those that would characterize any planet with an atmosphere, warmed at the equator and rotating from west to east. But the particular planet Earth has several characteristics peculiar to itself which modify the simpler planetary system. These terrestrial modifications result from (*a*) the inclination ($23\frac{1}{2}°$) and parallelism of the earth's axis, causing a uniform latitudinal shifting of the belts of solar energy during the course of a year; (*b*) a nonhomogeneous surface composed of both land and water areas, having contrasting temperature, pressure, and wind characteristics; and (*c*) land areas the surfaces of which are variable in configuration and altitude.

91. Latitudinal Shifting of the Wind Belts. Consequent upon the parallelism and inclination of the earth's axis, during the period of revolution the sun's vertical noon ray shifts from $23\frac{1}{2}°$N. (summer solstice) to $23\frac{1}{2}°$S. (winter solstice), a total of 47°. Of course it is not only the vertical ray that shifts but all the insolation belts as well and along with them the temperature belts, which are largely sun controlled. Pressure and wind belts, in part thermally induced, likewise may be expected to migrate latitudinally with the sun's rays (Fig. 56). This north-south shifting of the wind belts is by no means so simple a thing as it may appear to be from the above description, for it varies in amount and rapidity of shift from one part of the earth to another. In general there is a lag of a month or possibly two behind the sun. Over the oceans and along coasts where the migration is more readily observable the total migration is not great, usually not much over 10 to 15°. Over continents, on the other hand, the total latitudinal shift is greater, and the lag is considerably less than over oceans. Then, again, surface wind systems are much confused over land masses owing to surface irregularities and greater seasonal variations in temperature, so that the migration is not very evident. Instead of a simple latitudinal migration, the seasonal changes in pressure and winds are often to be observed in terms of shifts in position and intensity of the great continental centers of low and high pressure, which in turn result in a prevalence of different air masses in different seasons.

92. *Latitudes Covered by More than One Wind Belt.* This latitudinal shifting of the wind belts becomes climatically significant, especially in those regions lying in an intermediate position between two great wind systems or air masses of unlike weather conditions, as, for instance, between the westerlies on the one hand and the dry subsiding air of the subtropical highs on the other, or between the trades and the doldrums. Such a position assures the region of being encroached upon at the opposite seasons of the year by contrasting air masses and consequently of experiencing contrasting weather conditions. Ideally, three such transition regions should be present in each hemisphere, and there are evidences that they actually do exist, although in imperfect form and *certainly not as continuous latitudinal belts.*

a. Latitudes 5 ± to 15 ±° are intermediate in position between the humid doldrum air masses and the drier trades, the latter winds, often in modified form, prevailing at the time of low sun (winter), and the doldrums at the time of high sun (summer). One dry and one wet season should be the result. Even equatorward from latitude 5° there is some encroachment by the trades, although regions very close to the equator usually do not experience a strong and persistent tradewind influence. However, these winds are responsible for the less wet seasons of places near the equator.

b. Latitudes 30 to 40° are between the subtropical highs and the stormy westerlies. With the poleward migration of the sun's rays in summer the dry subtropical highs are shifted over these regions, whereas the westerlies with their cyclonic storms prevail in winter when the sun's vertical noon ray is in the opposite hemi-

sphere.[1] It is evident that this arrangement should give rise to dry summers and wet winters. Monsoon winds definitely interrupt this migration along the eastern sides and the interiors of the continents, so that it is chiefly present over the oceans and along western littorals.

c. Latitudes 60 to 70°, which mark the subpolar lows, are intermediate in position between the stormy westerlies and winds of polar origin so that a latitudinal shifting of winds should allow this region to experience both. The numerous cyclones which inhabit these latitudes tend to complicate and obscure any simple migration of wind belts. It is much more a region of alternating polar and modified tropical air masses. It is a fact, nevertheless, that in these higher latitudes there is a greater prevalence of cold polar air in winter and of warmer southwesterly currents in summer, suggesting a semblance of wind-belt and storm-belt migration.

93. Monsoon Winds. This terrestrial system of winds is characterized by a tendency toward a reversal in prevailing wind direction between winter and summer. It is directly the result of the earth's surface being composed of continents and oceans which have unequal heating and cooling qualities. (It has been noted in an earlier article that the effect of large land and water areas is to modify latitudinal wind belts, with the result that there are created semipermanent centers of high and low pressure with outblowing and inblowing winds.) If the earth's surface were composed of either all land or all water, monsoons could not exist. It needs to be recalled at this point that seasonal differences in temperature usually give rise to seasonal contrasts in pressure, and of course contrasts in pressure give rise to changes in wind direction. The chain of events, then, is from temperature, through pressure, to winds.

[1] As the term trade wind is used here it is intended to include winds having the same general character as trades, even if not from a northeast or southeast direction. For example, winds over the Mediterranean Basin in summer are prevailingly northwest. Yet these are essentially trade winds in both origin and character, even though modified in direction. This concept, expressed specifically for the trades, applies to the other wind systems as well.

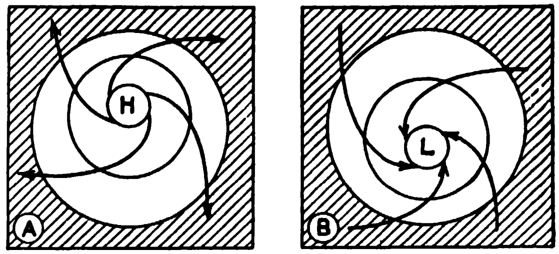


Fig. 41. Shaded areas represent oceans; white areas are continents. In winter (*A*) pressure is high over the cold continents, while in summer (*B*) it is low. The result is an outflow of continental air in winter and an inflow of ocean air in summer. This is a *monsoon* system. (*From Petterssen.*)

In winter, for example, the interior of Asia becomes excessively cold, resulting in the development of a great thermal continental anticyclone, or high-pressure center. Over the warmer seas to the east and south of Asia, temperatures are higher and the pressures, consequently, lower. As a result of this arrangement of the pressure areas the surface gradient is *from* the continent *toward* the ocean, with cold surface winds moving out from Asia toward the surrounding seas. This prevailing land wind constitutes the *winter monsoon* (Fig. 41*A*). (At higher elevation air is flowing from the ocean toward the continent, and it is this transfer of air from sea to land at higher elevations that creates the differences in surface pressure.) The low-pressure goal of the Asiatic winter monsoon lies south of the equator over the Indian Ocean and the hot interior of Australia. The winter monsoon is not always from the same direction in the various parts of eastern and southern Asia, for it blows from the west and northwest in Japan and North China and from the north and northeast in southern Asia, where it acts to strengthen the normal trade winds of those latitudes (Fig. 31). But although not always from the same direction, it is, in almost all sections, a polar air mass of continental origin bringing cold, dry air down to the very sea margins and beyond. This condition is not conducive to rainfall, so that winter is characteristically the driest season in monsoon lands. Winter monsoons, particularly those of middle latitudes, are liable to interruptions by the

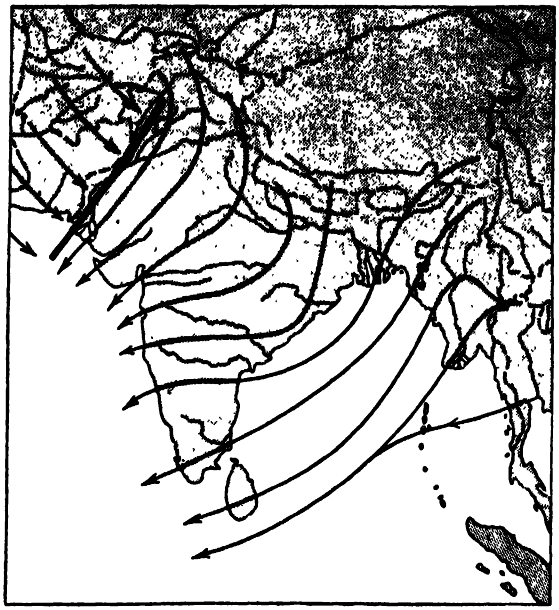


Fig. 42*A*

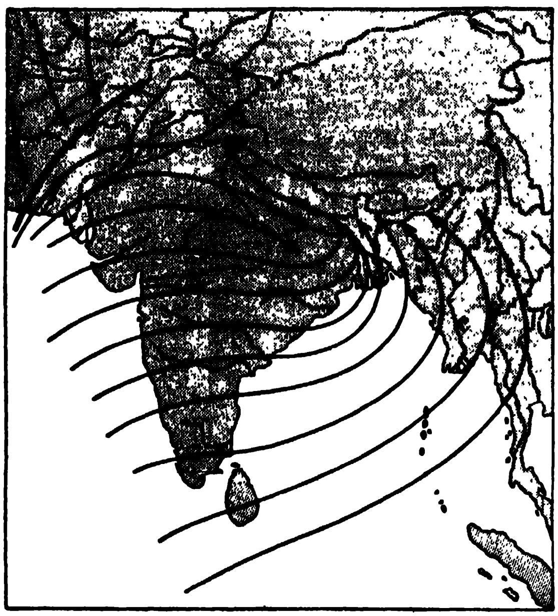


Fig. 42*B*

passage of cyclonic storms which bring some precipitation even in the cool season. The influence of passing cyclones and anticyclones is indicated by the table showing wind frequency in North China. Although land winds predominate in winter (67 per cent from west, northwest, and north), there are some from opposite directions; and in summer, although sea winds are most numerous (63 per cent from northeast, east, southeast, and south), winds from the continent are by no means absent (Fig. 29). In middle latitudes the winter monsoon is usually stronger than that of summer.

*Percentage of Wind Frequency in North China**

	N.	*N.E.*	*E.*	*S.E.*	*S.*	*S.W.*	*W.*	*N.W.*
Winter	17	8	5	6	6	8	18	32
Summer	10	9	12	26	16	10	7	10

* Kendrew. *Op. cit.* P. 97.

94. Summer Monsoon. In summer the Asiatic continent becomes warmer than the adjacent oceans, and as a consequence, a semi-permanent seasonal low-pressure center develops over that land mass. Higher pressure prevails over the cooler oceans, so that the gradient is *from* sea to land and so are the winds (Fig. 41*B*). This tropical maritime air mass moving in toward the heated continent is called the *summer monsoon* (Fig. 32). Much of it originates in the trades south of the equator. Since it travels great distances over bodies of tropical water, it brings with it abundant supplies of water vapor which are conducive to rainfall. Summer, therefore, is characteristically the wet season in monsoon lands.

The summer monsoon is not always a wind from the same direction throughout southeastern Asia, but at least it is from the sea and from tropical latitudes. Interruptions due to cyclonic storms are not infrequent. In monsoon regions continental-controlled winds tend to wipe out the planetary system of trades and westerlies, substituting in their places a terrestrial system. Hot, humid summers and relatively cold, dry winters are characteristic of most regions with continental wind systems in the middle latitudes. India, cut off as it is from the rest of Asia by high mountain ranges and plateaus, has a monsoon system of local origin, quite distinct from that of the rest of the continent (Figs. 42*A* and 42*B*). The following diagram will help to fix the chain of events described above for a monsoon region:

Winter—Asia cold—high pressure—surface winds toward the sea

Summer—Asia warm—low pressure—surface winds toward the land

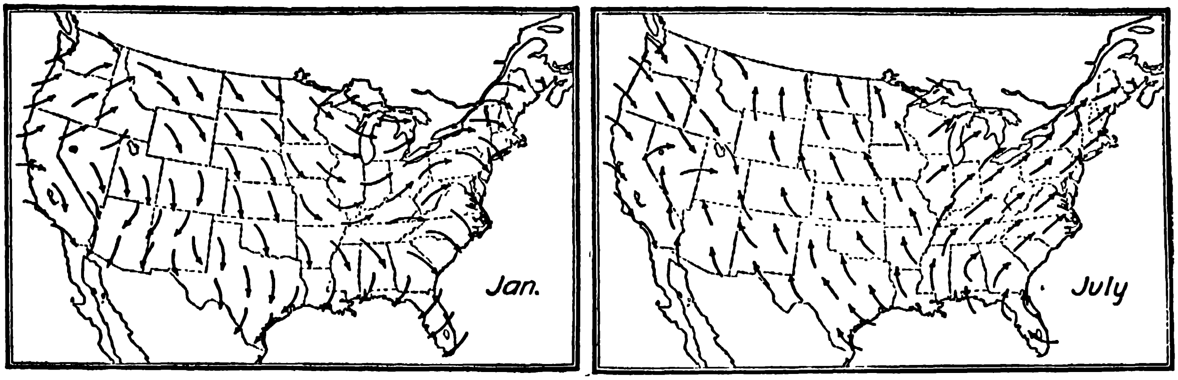


Fig. 43. Seasonal winds over the United States. Note the monsoon tendency over eastern United States. (*After Ward.*)

Partly owing to the great size of the continent, but also the result of fewer interruptions by cyclonic storms, the monsoon system of winds is most perfectly developed over eastern and southern Asia, although monsoons in modified form, or *monsoon tendencies*, are characteristic of other regions as well. Southeastern United States, northern Australia, Spain, and South Africa all are regions with monsoon tendencies. These land areas may not be always sufficiently powerful to cause a complete seasonal reversal of winds, as does Asia, but at least they create partial monsoons which greatly affect the seasonal weather (Figs. 43, 44*A*, and 44*B*).

It is conspicuous that regions with strong monsoon tendencies usually are on the eastern sides of continents. This is especially true in the middle latitudes, since the western or windward coasts are so distinctly marine in character, with only small changes in temperature from summer to winter. It is, therefore, only on the more continental eastern, or leeward, sides that sufficiently large seasonal extremes of temperature can develop to produce a wind reversal.

95. Minor Terrestrial Winds. *Land and Sea Breezes.* Just as there are *seasonal* wind reversals (monsoons) resulting from seasonal temperature contrasts between land and water,

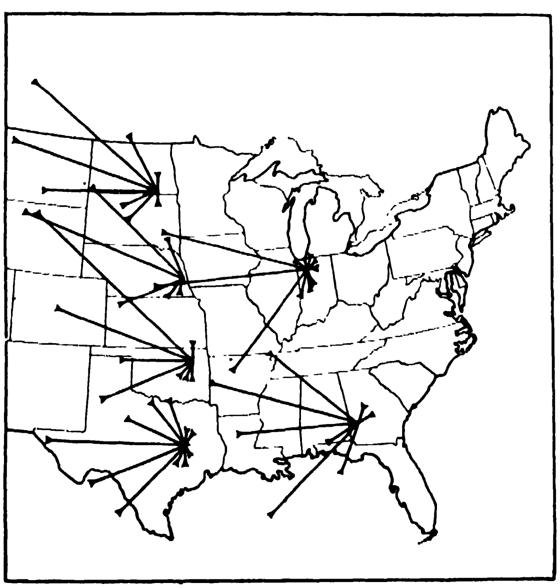


Fig. 44*A*. Prevailing direction of upper winds over eastern United States in winter. They are more northwesterly in the cool season. (*Courtesy U.S. Weather Bureau.*)

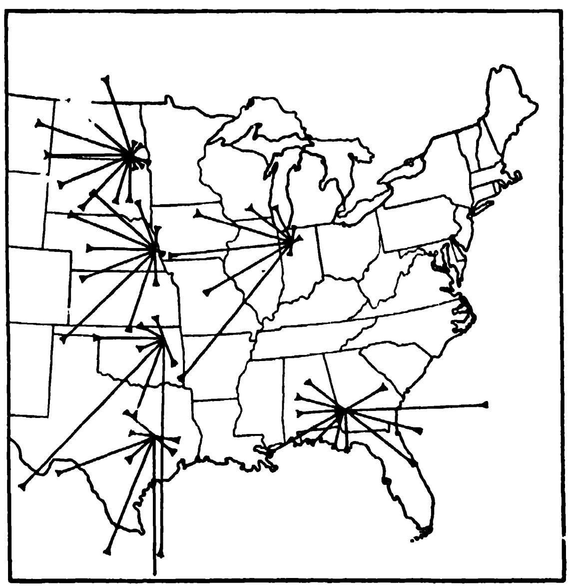


Fig. 44*B*. Prevailing direction of upper winds over eastern United States in summer. They are more southwesterly in the warm season. (*Courtesy U.S. Weather Bureau.*)

so there are *diurnal*, or daily, monsoons resulting from similarly induced temperature contrasts within the 24-hr. period. These are called *land and sea breezes*, or *diurnal monsoons*. Thus along coasts there is often a drift of cool, heavy air from land to water at night (corresponding to winter) and a reversed wind direction, sea to land, during the heat of the day (corresponding to summer). Usually the sea breeze begins between 11:00 and 12:00 A.M. and seldom lasts much later than 4:00 P.M. It is a shallow wind, penetrating only a short distance inland, usually not over 20 miles. Along tropical littorals the sea breeze is a remarkably important climatic phenomenon, causing them to be more livable and healthy places than they otherwise would be. The beginning of the sea breeze may cause a drop in temperature of 15 to 20° within ¼ to ½ hr. At Joal, Senegambia (West Africa), the temperature at 12:30 P.M. on an April day was 100°F., with a land wind from the northeast and a relative humidity of 3 per cent. At 12:45 the wind direction was northwest, from the sea, temperature had dropped to 82°F., and the relative humidity had risen to 45 per cent (Hann). Coasts with well-developed sea breezes are inclined to have modified marine climates, with the daily temperature maxima much reduced.

96. *Mountain and Valley Breezes.* Like land and sea breezes, these local winds have a distinct diurnal periodicity. During the day the air of an enclosed mountain valley, or that adjacent to a slope receiving relatively vertical rays of the sun, becomes warmer than air at the same altitude over the adjacent plain, so that active convectional ascent of the warm and expanded air takes place up the valleys and along the mountain slopes. This daytime updraft of warm air, or *valley breeze*, is indicated by the masses of cumulus clouds which collect about the peaks of mountains during summer days. They are the "visible tops of invisible ascending air currents." Daily summer afternoon rains are therefore common in mountains, and visibility, because of the cloud masses, is restricted during the warm hours of the day. After sundown, as the rapidly cooling slopes begin to chill the air layers next to them, the cooler, heavier air begins to slip down the mountainsides into the valleys. This is a reversal of the day current and is known as the *mountain breeze*. It is often very perceptible at the mouth of a gulch; and where there are marked constrictions in a valley that drains a large area, strong winds may result. Summer camps are sometimes pitched at the mouth of a valley in order to benefit from the cooling effect and ventilation provided by the mountain breeze.

Ocean Drifts and Currents

The discussion of the movement of ocean waters is included within the climatic section of this book chiefly because ocean currents are one of the controls of climate, and a knowledge of their characteristic systems is useful in an understanding of world climates. It should be added also, as a further reason for their inclusion at this point, that the drift of ocean waters is climatically induced, winds, temperature, precipitation, and humidity contrasts being the principal direct or indirect motivating agents.

97. Scheme of Surface Drifts and Currents in an Individual Ocean. Except in the polar seas, there is a tendency for all the other great oceans to exhibit general circulations of surface currents and drifts, which, in many of their broader aspects, greatly resemble each other (Figs. 45 and 46). Fundamentally surface ocean currents are related to the direction of the prevailing wind. The scheme of ocean currents as developed in the North Atlantic, which is reasonably representative of those of other seas as well, will be taken as an example for analysis.

The most conspicuous element of the North Atlantic circulation is probably the great, closed elliptical whirl about the subtropical Azores high. The trade winds on the equatorward sides of the subtropical highs in both hemispheres tend to drift the surface waters before them across the ocean. The deflective force of earth rotation, right in the Northern and left in the Southern Hemisphere, acts to make this a westward-flowing current, moving somewhat at an angle to the

moving winds from the subtropical whirls drive the surface waters toward lower latitudes. Owing to the deflective force of earth rotation, the ocean currents along these cool-water coasts have a component of movement away from the land. Colder water from below, therefore, rises to replace the surface water.

99. Climatic Significance of Ocean Currents. *Temperature.* In order that an ocean current may have direct and marked effect upon the temperature of the adjacent land mass, it is obvious that the winds must be onshore. Such is the case in northwestern Europe, where westerly winds carry the effects of the warm North Atlantic Drift far into the continent. Parts of coastal Europe are 30 to 40° too warm in January as compared with the normal for their latitudes. In contrast, the warm waters paralleling the east coasts of the United States and Japan are much less effective as direct temperature controls, because the winter winds are prevailingly offshore. Nevertheless, the relatively frequent east winds on the fronts of cyclonic storms create sporadic importations from off the mild waters and thereby tend to raise the normal winter temperature. Where cool ocean currents parallel coasts, temperatures along the adjacent littorals are likely to be markedly lowered. Thus the coast of Peru, which is paralleled by the cool Peru Current, is 10° cooler than the coast of Brazil in a similar latitude, where a warm current prevails.

It has been stated previously that there is a tendency for cool and warm ocean currents to converge along the western sides of oceans and to diverge along the eastern sides. Where contrasting currents *converge*, the effect is to squeeze the isotherms closer together, making for marked latitudinal temperature contrasts, steep temperature gradients, and advection fogs. This condition is found, for instance, along the east coasts of Asia and North America. Where contrasting currents *diverge*, they tend to spread the isotherms, making for milder temperature gradients. This is the case in the eastern Atlantic. It must not be inferred, however, that ocean currents are the principal cause of these temperature-gradient phenomena on the opposite sides of oceans; at best they are only auxiliary causes cooperating with more powerful marine and continental influences.

100. *Fog and Precipitation.* Cool-water coasts in low latitudes often present the unusual situation of being characterized by both fog and aridity—an apparently contradictory combination. The fog is the result of warm air from over the ocean proper being chilled by blowing over the cool current lying alongshore and mixing with the air above it. It may then be drifted in over the land, but usually it is confined to a narrow coastal fringe. The aridity is the result of the chilling of the base of a tropical maritime air mass as it moves landward over cool ocean waters. Such a cooling of the lower layers increases their density and creates a temperature inversion, so that the air mass is made more stable and is opposed to rising, a process that might produce rain. Where a cold current parallels a tropical coast, therefore, dry climates and fog are likely to prevail. In western Peru, desert conditions are carried to within 5° of the equator by the effects of the cool Peru Current, and as it moves westward away from the continent the whole equatorial eastern Pacific is aridified by the cool waters. Other cool currents such as the Benguela off southwest Africa, the Canaries off northwest Africa, and the California off southern California and northwestern Mexico similarly cool, fog, and aridify the coast lands adjacent to them. In these regions, as along many other cool-water coasts, upwelling is an important item. Where warm currents lie offshore, they tend somewhat to amplify the atmospheric humidity and to increase the rainfall.

101. *Indirect Climatic Effects of Ocean Currents.* Indirectly ocean currents may affect the general climatic character of an adjacent land area by their influence upon the routes of cyclonic storms. This indirect influence applies to leeward as well as to windward coasts. Cyclones are attracted by the relatively high temperatures and consequent low pressures associated with large masses of warm surface water. The location of one of the world's principal storm tracks, lying southeast of Iceland, is associated in a cause-and-effect relationship with the warm

waters of the North Atlantic Drift. It has been observed that when the "Gulf Stream" along the American South Atlantic Coast is stronger and warmer than usual, so that pressures in that vicinity are below normal, cyclonic storms in eastern United States tend to travel more southerly routes, giving that part of the country abnormally cold and snowy winters. A weak "Gulf Stream" and associated higher pressures, on the other hand, result in the storm tracks being shifted farther poleward, and a milder, less snowy winter is the result. In this instance there is the anomalous situation of an excess of warm water offshore indirectly causing an abnormally cold and snowy winter, while a minimum of warm water induces a milder one.

when condensation takes place, cooling is retarded by the liberation of so much latent heat.

Evaporation—heat consumed

Solid	Liquid	Gas
(ice)	(water)	(water vapor)

Condensation—heat released

106. The Condition of the Atmosphere as Regards Moisture. The capacity of the air for water vapor depends very largely upon its temperature.[1] That the capacity advances at an increasing rate with higher temperatures is indicated by the following table. Thus by increasing the temperature of a cubic foot of air 10°, from 30 to 40°, the moisture capacity is advanced only 1 grain, while a similar 10° increase, from 90 to 100°, results in an increase of 5 grains. It is evident that the air on a hot summer day is able to contain much more moisture than is cold winter air and is likely, therefore, to have greater potentialities for abundant precipitation. Air over Madison, Wis., in July has a water-vapor capacity seven to eight times what it is in January. When a given mass of air contains all the water vapor that it is capable of retaining, it is said to be *saturated.* The condition of the air as regards water vapor is spoken of as *humidity.* If air is completely dry, its humidity is zero.

Maximum Water-vapor Capacity of 1 Cu. Ft. of Air at Varying Temperatures

Temperature, Degrees Fahrenheit	*Water Vapor, Grains*	*Difference between Successive 10° Intervals*
30	1.9	
40	2.9	1.0
50	4.1	1.2
60	5.7	1.6
70	8.0	2.3
80	10.9	2.9
90	14.7	3.8
100	19.7	5.0

[1] Although it is customary to speak of the *capacity of the air* for water vapor, actually the air itself has practically no effect in this respect. A cubic foot of space and a cubic foot of air at the same temperature can contain essentially the same amount of water vapor.

107. *Absolute Humidity.* The total amount of water vapor that a given mass of air contains, expressed in weight of the water vapor per unit *volume* (as grains per cubic foot), is called its *absolute humidity* (vapor pressure). Since it expresses the actual water-vapor content of air, it is of some significance in gauging the atmosphere's possibilities for precipitation. Air over the north-central part of the United States in July has 3.5 to 5.5 times greater absolute humidity than has the January atmosphere. It is usually highest in the vicinity of the equator and decreases toward the poles, varying considerably, however, with distance from oceans and from more minor sources of moisture. It is commonly higher in summer than in winter and is usually greater during the day than at night, all these principal items of distribution being largely controlled by temperature.

108. *Specific Humidity.* Specific humidity is defined as the *weight* of water vapor in a unit *weight* (not volume) of air. It is usually expressed in grams of water vapor per kilogram of air. As a mass of air rises or subsides its volume changes and hence its absolute and relative humidities, but specific humidity is not affected since the relative weights of water vapor and air have not been altered. Specific humidity therefore has much more value in identifying air masses as they move from place to place or as they rise and subside.

109. *Relative Humidity.* Relative humidity is always expressed in the form of a ratio, fraction, or percentage. It represents the amount of water vapor actually present in the air (absolute humidity) compared with the greatest amount that could be present at the same temperature. When the relative humidity reaches 100 per cent the air is said to be saturated. As an illustration: Air at 70° can contain approximately 8 grains of water vapor per cubic foot. If it actually contains only 6 grains (its absolute humidity), then it is only three-fourths saturated, and its relative humidity is 75 per cent. Relative humidity can be altered either by changing the amount of water vapor or by varying the capacity of the air, *i.e.*, changing its temperature. The following table shows how air which was

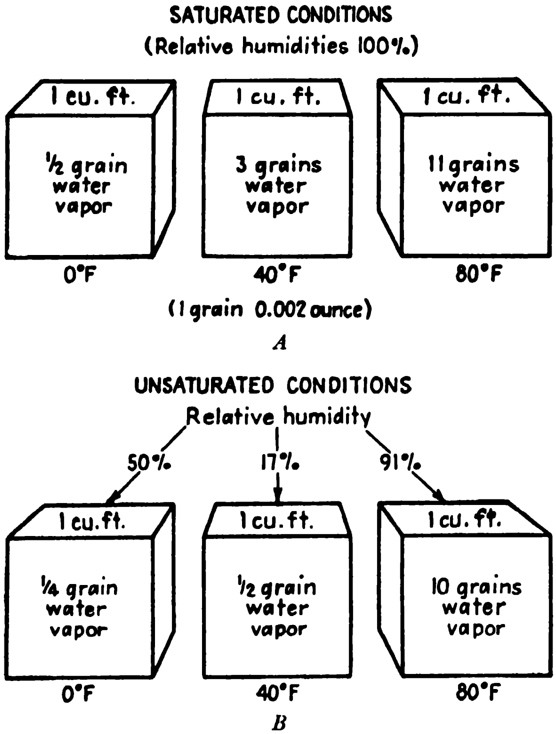


Fig. 48

saturated at 40° acquires successively lower relative humidities simply by increasing its temperature, the water-vapor content remaining unchanged. Relative humidity is an important

Temperature, Degrees Fahrenheit	*Absolute Humidity, Grains*	*Relative Humidity, Per Cent Saturated*
40	2.9	100
50	2.9	71
60	2.9	51
70	2.9	36
80	2.9	27
90	2.9	19

determinant of the amount and rate of evaporation; hence is a critical climatic factor in the rate of moisture and temperature loss by plants and animals, including human beings. Various humidity relationships are illustrated by Figs. 48*A* and 48*B*. Figure 48*A* shows a cubic foot of air subject to three different temperatures. At 0°F. only $\frac{1}{2}$ grain of invisible water vapor can exist in a cubic foot. If the temperature rises to 40°F., nearly 3 grains of water vapor can exist in that same cubic foot of air, and at 80°F. there can be nearly 11 grains of water vapor in the same space. In all these cases, saturation conditions, or 100 per cent relative humidities, are assumed. If any of the cubes in Fig. 48*A* is cooled appreciably, the invisible water vapor will be condensed out as visible water or ice particles.

In Fig. 48*B* the same cubic-foot samples are shown except that they now represent unsaturated conditions; *i.e.*, they do not contain all the water vapor possible at those temperatures. The cube on the extreme left has only $\frac{1}{4}$ grain of water vapor. Since this is only one-half of what can be present under saturated conditions (see cube at left in Fig. 48*A*), the relative humidity is therefore $\frac{1}{4}$ grain divided by $\frac{1}{2}$ grain, or 50 per cent. The middle cube in Fig. 48*B* contains only $\frac{1}{2}$ grain of water vapor as compared with nearly 3 grains at saturation, making a relative humidity in this case of about 17 per cent. The same reasoning gives a relative humidity of about 91 per cent for the cube on the extreme right. A comparison of the cube on the extreme left in Fig. 48*A* with the center cube in Fig. 48*B*, *both of which contain identical amounts of water vapor*, reveals the former with 100 per cent relative humidity and the latter with only 17 per cent. This explains why relative humidity ordinarily goes down as temperature rises on a hot summer day and rises as temperature falls on a cool night.

110. *Dew Point and Condensation.* If air that is not saturated is sufficiently cooled, its capacity for moisture thereby being reduced, a temperature is eventually reached at which the mass of air is saturated, even though the amount of water vapor has not been altered. This critical temperature at which saturation is reached is called the *dew point.* If air is cooled below the dew point, then the excess of water vapor, over and above what the air can contain at that temperature, is given off in the form of minute particles of water (if above 32°) or sometimes ice (if below 32°) and *condensation* has taken place. For example, when the temperature of the air is 80° and the absolute humidity 8 grains of water vapor per cubic foot, then the relative humidity is 73 per cent (Table, page 73). If this mass of air is gradually reduced in temperature

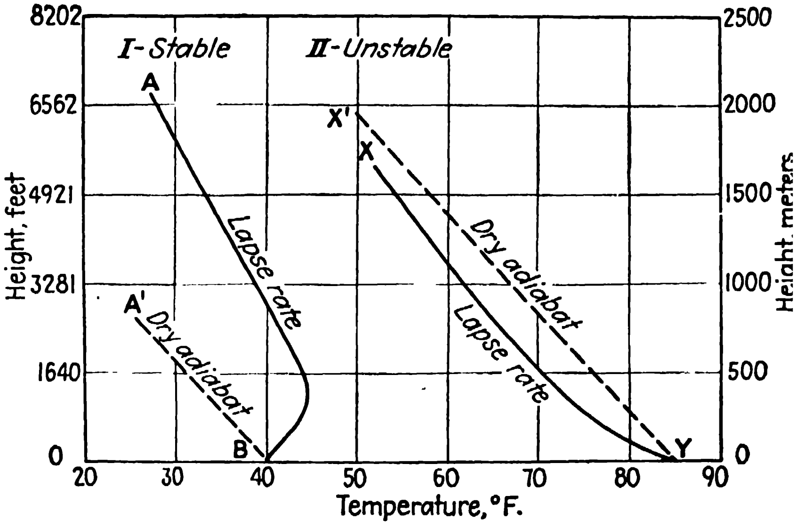


Fig. 51. Atmospheric stability and instability.

ity of precipitation. When air from a warm ocean flows over a cool current, the lower air is chilled and the air mass is made more stable. Likewise in winter when a mild air mass from the Gulf of Mexico flows northward into the continental United States over a colder and perhaps snow-covered land surface, its base is cooled with a resultant increase in the stability of the air. To be sure the surface chilling may result in fog, but on the other hand precipitation is very unlikely. In terms of methods of origin, fog and precipitation are commonly opposites. The relative stability of an air mass may be determined by noting its vertical temperature distribution or the lapse rate. A small lapse rate (less than the adiabatic rate, or $5\frac{1}{2}$°F. per 1,000 ft.) and especially one in which the temperature *increases* with altitude, indicates stable air (Figs. 51 and 52).

117. Instability. When air does not resist vertical displacement but, on the contrary, has a tendency to move upward away from its original position, a condition of *instability* prevails. Under such conditions vertical movement is prevalent and cloud and precipitation are likely. Instability may be likened to a cone delicately balanced upon its small apex, for here the slighest impulse will cause it to tip over. Instability is characteristic of warm humid air in which there is a rapid vertical decrease in temperature and humidity, *i.e.*, a steep lapse rate. When the lapse rate is greater than the adiabatic rate of $5\frac{1}{2}$°F. per 1,000 ft., a condition of instability prevails (Fig. 51). Instability may be developed in an air mass if it is warmed and humidified in its lower layers. In summer when air from the Gulf of Mexico flows in over the warm land of the Cotton Belt states it is heated from below, made unstable, and much thunderstorm rainfall results. In the equatorial regions of the earth the sultry humid air is prevalently unstable. When humid air that is mildly stable is *forced* to rise

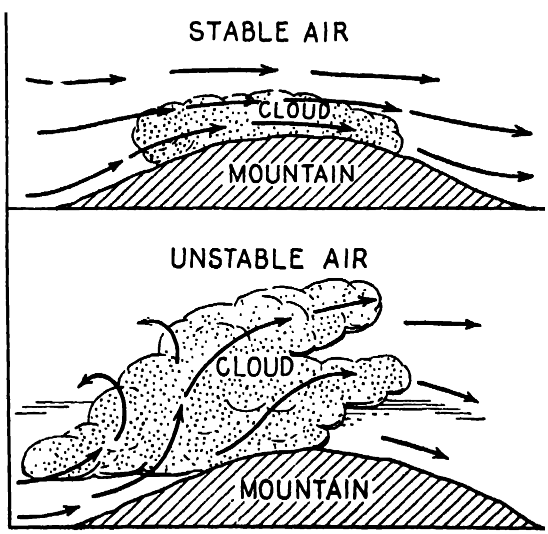


Fig. 52. Stability and instability in saturated air.

over mountain barriers or over colder wedges of air the resulting condensation may add so much heat to the ascending air that it becomes actually unstable and so continues to rise with accompanying heavy precipitation. Such humid air, that was originally stable but was made unstable as a result of forced ascent and condensation, is said to be *conditionally unstable*.

118. Stages in the Cooling of a Rising Air Mass. As a mass of unsaturated air rises, no matter for what reason, it begins to cool at the normal rate of about 5.5° per 1,000 ft. of ascent. Until it has risen and cooled sufficiently for the saturation point to be approached, there are no condensed liquid or solid particles in the ascending air. All humidity is in vapor form. For this reason this first stage, without condensation, is called the *dry stage*.

Eventually the ascending and cooling air reaches the dew point, condensation begins, or is greatly accelerated, and the rising air enters the *cloud-and-rain stage*. The air still contains much moisture in vapor form, but some of it has been converted into liquid form. Here clouds, composed of minute water particles, begin to form. As condensation commences, heat of condensation is released into the rising air, so that cooling is at a slower rate.

It is possible for ascending air to pass somewhat beyond the condensation level, with a resulting formation of clouds, and still yield little or no precipitation. The first condensation takes place around almost innumerable hygroscopic dust nuclei, the individual condensed water particles being so small that they fall very slowly and are probably evaporated before they reach the earth's surface. Gray, overcast, cloudy days with no rain are consequently very common. However, if the air continues to ascend well above condensation level, more and more of these multitudes of condensation nuclei are left behind, literally strained out of the ascending air because of their greater density or weight, so that further condensation must take place around fewer nuclei. As a result of the drops forming around fewer nuclei, they grow large enough to overcome the force of the ascending air, fall and eventually reach the earth. Growth in size of drops is further aided by (*a*) intense turbulence and (*b*) electrical attraction.

There is some reason to believe that large-scale precipitation at least in the middle latitudes may not be released from a cloud until it builds up to such heights that ice crystals begin to form. The ice crystals seem to have the same function in releasing precipitation that condensation nuclei have in starting condensation. They perform like very active nuclei in the growth of raindrops. It may be that most of the moderate to heavy rainfall of the earth is the result of ice crystals falling through clouds composed of supercooled droplets, during which process there is a very rapid growth of large drops around the ice nuclei. Man-made precipitation has actually been produced by sowing clouds with dry-ice particles dropped from an airplane.

When the ascending and cooling air finally reaches a temperature of 32°, some of the condensed liquid particles *already in the air* probably are changed into ice. That not all of them are frozen, but that some continue to exist in liquid form at temperatures well below freezing, is indicated by the fact that ice frequently collects on airplanes. Clouds composed of supercooled water droplets and with no ice particles have been observed at temperatures as low as −4°F., or 36° below freezing. As the air continues to rise above the freezing level, and cooling continues, much, although not necessarily all, of the subsequent condensation is in the solid form. In this stage, known as the *snow-and-ice stage*, water vapor in the form of a gas may pass directly into the solid form, molecule by molecule, and build a tiny ice crystal. Therefore clouds at these subfreezing temperatures commonly are composed of minute ice crystals, although supercooled liquid particles may be present as well. Snowflakes are simply agglomerations of these tiny ice crystals.

CLOUD CLASSIFICATION AND TYPES

119. Clouds are reliable indicators of weather conditions, and for this reason an elementary knowledge about types of clouds is of value to the student of physical geography. The forms and appearances of clouds are one element of

grow so high that they become cumulo-nimbus and produce precipitation of the thunderstorm type.

10. *Cumulo-nimbus* are overgrown cumulus which have reached such a height that they lose their clear-cut cauliflower shape. They often spread out on top and become anvil-shaped. Such clouds are associated with sharp showers, squall winds, lightning and thunder, and sometimes hail.

FORMS OF PRECIPITATION

120. *Rain*, which is the commonest form of precipitation is, as stated previously (118), the result of condensation in rising air currents at temperatures usually above 32°, while *snow* forms at temperatures below freezing. The fundamental form of snow is the intricately branched, flat, six-sided crystal in an almost infinite variety of patterns. Numerous crystals matted together form a snowflake. On the average it requires about 1 ft. of snow to equal an inch of rain. *Sleet* is frozen rain and results when raindrops from a warmer air mass above fall through a cold surface layer of air. It is characteristic of the cooler seasons. *Glaze* is really not a form of precipitation but is the accumulation of a coating of ice on objects near the earth. Fortunately it is not of common occurrence, for the so-called *ice storm* which produces glaze is one of the most destructive of the cool-season types of weather. It occurs when rain, near or below the freezing point, strikes surface objects the temperatures of which are below 32° and is immediately converted into ice. So great may become the weight of the ice accumulation that trees are often wrecked, telephone, telegraph, and electric wires broken, and their poles snapped off. *Hail*, although the heaviest and largest unit of precipitation existing in solid form, is exclusively the product of vigorous convection, occurring in thunderstorms, which in turn usually belong to the warm season. Hailstones in the form of spheres or irregular lumps of ice are either transparent or are composed of alternating concentric layers of clear ice and opaque layers of partially melted snow.

TYPES OF AIR ASCENT AND PRECIPITATION RESULTING

It already has been noted that rising air cools and that, if the temperature of sufficiently large masses of humid air is reduced well below the dew point, abundant condensation and precipitation will result. It remains now to analyze the conditions under which large masses of air may be caused to ascend. Three classes of origin will be noted, but it should be borne in mind that it is common for the types to be intermingled and interrelated.

121. Convectional Precipitation. As a result of the heating of surface air it expands and is forced to rise by the cooler, heavier air above and around it. Ordinarily such rising air, since it cools at nearly double the rate of the normal vertical temperature decrease, will rise only a few thousand feet before its temperature has been reduced to the point where it is the same as that of the surrounding air. At that point where the rising air reaches air strata of its own temperature and density, further ascent ceases. But if abundant condensation begins before this stage is reached, then heat of condensation is released, so that, with this added source of energy, the rising air will be forced to ascend much higher before reaching atmospheric strata of its own temperature. Thus on a hot summer afternoon, when surface heating is intense and condensation abundant, the towering cumulo-nimbus clouds resulting from convectional ascent may be several miles in vertical depth, and precipitation from them may be copious.[1]

Thermal convection does not consist of the lifting of a widespread air mass, but rather it is in the form of local ascending and descending currents of relatively small horizontal dimensions. Consequently the cumulo-nimbus clouds associated with the ascending currents are not of great horizontal extent, so that each appears to be single and isolated and there is frequently clear sky between the individual cumuli. Because the cumulo-nimbus cloud is not extensive in character, the rainfall associated with it is

[1] Thunderstorms and their rainfall are dealt with in greater detail in the next chapter on storms.

usually of short duration. We speak of it as a thunder *shower* rather than as a thunder *rain.* Since convectional ascent is essentially a vertical movement of warm humid air, cooling is rapid and the associated rainfall is likely to be vigorous. Because convectional rain commonly comes in the form of heavy showers, it is less effective for crop growth, since much of it, instead of entering the soil, goes off in the form of surface drainage. This is a genuine menace to plowed fields, since soil removal through slope wash and gullying is likely to be serious. On the other hand, for the middle and higher latitudes, convectional rain, since it occurs in the warm season of the year when vegetation is active and crops are growing, comes at the most strategic time. Moreover, it provides the maximum rainfall with the minimum amount of cloudiness. Convectional showers resulting from surface heating are associated with warm regions and warm seasons. This type of rain reaches its maximum development in the wet tropics where heat and humidity conditions are relatively ideal for promoting local convection. In the middle latitudes it is most common in the warmer subtropical portions and is confined largely to the warmer seasons of the year. Clearly local convection is closely associated with high temperature.

Of a somewhat different origin is rainfall resulting from the overrunning of warm and less dense air by colder, denser currents aloft. When this occurs atmospheric overturning is likely, the cool, heavy air sinking to the earth and forcing the warm air upward, often violently. Heavy downpours may result.

Still another type of convectional precipitation is associated with humid stable air masses for which the initial upward thrust is provided by some obstacle, such as a mountain range or a cold wedge of air in a cyclonic storm. When condensation begins, so much heat of condensation may be added to the reluctantly ascending air that it eventually becomes unstable and buoyant, and convective ascent then carries it on to greater heights with convectional showers resulting. Such rain is a combination of orographic and convectional or of cyclonic and convectional.

122. Orographic Precipitation. Large masses of air may be forced to rise when landform barriers, such as mountain ranges, plateau escarpments, or even high hills, lie athwart the paths of winds. Since water vapor is largely confined to the lower layers of atmosphere and rapidly decreases in amount upward, heavy orographic rainfall is the result of such forced ascent of air, associated with the blocking effect of landform obstacles. Witness, for example, the very abundant precipitation along the western or windward flanks of the Cascade Mountains in Washington and Oregon, along parts of the precipitous east coast of Brazil, which lies in the trades, or bordering the abrupt west coast of India, which the summer monsoon meets practically at right angles. The *leeward* sides of such mountain barriers, where the air is descending and warming, are characteristically drier (Fig. 54). This is called the *rain shadow.* The blocking effect of a mountain is normally felt at some distance out in front of the abrupt change in slope, the approaching wind riding up over a mass of stagnant air along its front. The most ideal con-

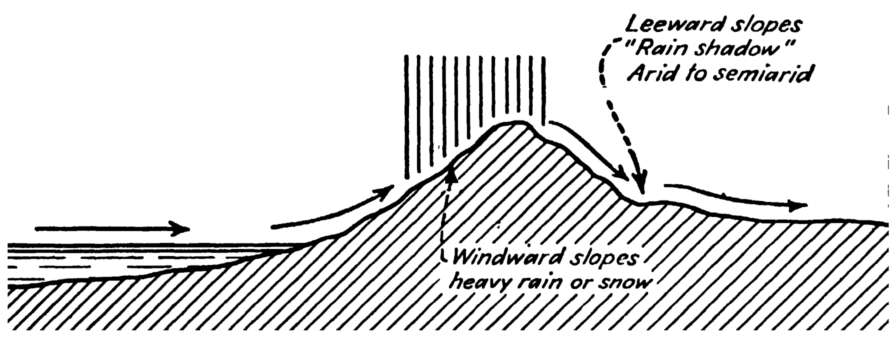


Fig. 54

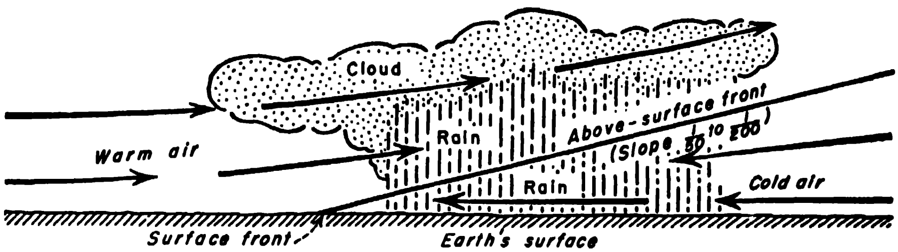


Fig. 55. Illustrating the origin of frontal rainfall.

dition for producing heavy orographic rainfall is when a high and relatively continuous mountain barrier lies close to a coast and the winds from off a warm ocean meet the barrier at right angles. Orographic rains have less seasonal and daily periodicity than do those of convectional origin. In monsoon regions, very naturally, the maximum is at the time when air is moving from sea to land, usually high sun, or summer. In other regions the strength of the winds, the angle at which they meet the mountain barrier, or the contrast between land and water temperatures may determine the season of maximum orographic rainfall.

It seems likely that a considerable part of the precipitation associated with highlands is not the result of direct forced ascent of the prevailing winds, in other words, not purely orographic in type. Certainly of great importance are such indirect effects as (*a*) the production of convectional currents up mountain slopes exposed to strong insolational heating; (*b*) the "pinching" or "blocking" effect upon cyclonic storms; and (*c*) the providing of a "trigger" effect that gives the initial upthrust to conditionally unstable air masses. Sometimes only a slight amount of lifting is necessary to bring these air masses to condensation level, after which they become unstable and so continue to rise, yielding abundant rainfall. Thus highlands of less than 3,000-ft. elevation, although perhaps inducing no great amount of direct orographic precipitation, may by these indirect means become much rainier areas than the surrounding lowlands.

123. Cyclonic and Frontal Precipitation.[1] In low-pressure storms (cyclones) of middle latitudes air from various directions, and consequently of different temperatures and densities, tends to converge toward a center. As a result of convergence and consequent lifting, plus the underrunning of warmer, lighter air masses from lower latitudes by colder, denser air currents from higher latitudes, large volumes of air are caused to ascend (Fig. 55). Unlike convectional ascent, which involves direct vertical lifting, the warmer air in cyclones more often rises obliquely, and therefore slowly, along mildly inclined surfaces of cold, dense air, and cooling as a consequence is less rapid. As a result of the slower ascent and cooling, precipitation in cyclones is characteristically less violent than in thunderstorms and is inclined to be steadier and longer continued. The dull, gray, overcast skies and drizzly precipitation of the cooler months in middle latitudes, producing some of the most unpleasant weather of those seasons, are usually associated with cyclones. When overrunning of warm surface air by cooler currents aloft occurs in a cyclone, heavier downpours may occur. These storms and their associated fronts are most numerous and best developed during the cool season. Where they dominate weather conditions, therefore, they tend to produce fall or winter maxima in precipitation curves. Most of the winter precipitation of lowlands in the middle latitudes is cyclonic or frontal in origin.

In the tropics, as well as in the middle latitudes, cyclones and fronts are important generators of precipitation. Convergence of air and consequent ascent are characteristic of all low-pressure storms, whether in low or in middle latitudes. Along the intertropical front in equatorial regions, much rainfall is associated with the large-scale convergence where the two relatively homogeneous trade winds meet. Although a true front, with associated overrunning,

[1] Cyclones and their precipitation are considered in greater detail in the following chapter on storms.

is many times absent, the convergence itself results in great masses of warm humid air being lifted high above the earth's surface with resulting heavy precipitation.

DISTRIBUTION OF PRECIPITATION

124. Important Precipitation Data. At least three items concerning precipitation of a region are of outstanding importance: (*a*) its total average amount, or depth, for the year (Plate I); (*b*) its seasonal periodicity; and (*c*) its dependability, both annual and seasonal (Fig. 92).

125. The *amount* of annual rainfall varies widely over the earth, numerous stations recording on the average less than 5 in., while there are a few where it exceeds 400 in. It is this total average yearly amount of rainfall which usually receives the principal attention, although this practice cannot be defended. Geographically speaking, the fact that Omaha, Neb., receives 30 in. of rainfall annually is no more significant than the fact that 17.4 in. (58 per cent) falls during the months from May to August and only 3.3 in. (11 per cent) falls during the period November to February.

126. *Seasonal distribution* of precipitation becomes of greatest importance in the middle latitudes where there is a dormant season for plant growth imposed by low temperatures, *i.e.*, the winter season. In the tropics where frost is practically unknown except at higher elevations, rainfall is effective for plant growth no matter at what time of year it falls. In the middle latitudes, however, only that proportion of the annual precipitation which falls during the frost-free season may be called effective. In the more severe climates a strong concentration of rainfall in the warmer months when plants can use it is desirable. Time of occurrence, therefore, is coequal in importance with amount.

127. *The dependability* or reliability of the annual or seasonal precipitation is an expression of its variability (Fig. 92). Data on rainfall reliability are scarcely less important than those concerned with amount and seasonal distribution. Variability may be defined as the deviation from the mean computed from 35 years or more of observations. In humid climates the annual variability is usually not greater than 50 per cent on either side of the mean, *i.e.* the driest year may have about 50 per cent of the normal value while the wettest year may have 150 per cent. In dry climates these values vary between about 30 and 250 per cent. It is a general rule that variability increases as the amount of rainfall decreases. It is an inverse ratio. Variability of precipitation must be taken into consideration when agricultural plans are made, for it is only normal that there will be years when the precipitation is less than the average. In semiarid and subhumid climates where crop raising normally depends on a small margin of safety, variability is of utmost concern. Moreover the agriculturist in such regions must bear in mind that negative deviations from the mean are more frequent than positive ones, which indicates that a greater number of dry years are compensated for by a few excessively wet ones. Variability of seasonal and monthly amounts are even greater than those for annual values.

128. *Intensity and Probability.* There are many other types of useful precipitation data, although most of them are probably of less value than the three mentioned previously. For example the number of rainy days (defined as one having at least 0.01 in. of rainfall) compared with the total amount of annual rainfall is an indication of the way the rain falls, or its *intensity*. At London, England, the annual rainfall of about 25 in. is spread over 164 rainy days which indicates a lower intensity than the conditions at Cherrapunji, India, where 440 in. falls in 159 days. The probability of rainy days is a kind of data which have considerable value to such people as farmers and resort owners. This may be readily computed by dividing the number of rainy days in a month or a year by the total number of days.

129. Zonal Distribution of Precipitation. Since precipitation is almost exclusively produced by adiabatic cooling in ascending air currents, it follows that the zones of most abundant precipitation on the earth are where ascent of air is most frequent and most pronounced. The principal regions of ascent are (*a*) along the windward sides of mountain ranges and (*b*) the

the westerlies which have migrated farthest equatorward during the cool season. During high sun its weather is dominated by the dry subsiding air masses of the subtropical highs. Zone 6 resembles Zone 5 in that it has winter rain and summer drought, and the controls producing this regime are identical in both cases (Fig. 57). Because Zone 6 is farther removed than Zone 5 from the drought-producing controls of summer and nearer to the middle-latitude cyclonic tracks and frontal zones in winter, its total rainfall is greater, its winter wet season longer, and its summer drought period shorter. Zone 7, lying in the middle-latitude zone of convergence where cyclones and fronts are numerous, has precipitation at all seasons. Usually the interiors of continents have some accent upon the summer season. Zone 8, both because of the low temperature and the prevalence of an anticyclonic system with subsiding air masses, is a region of meager precipitation at all seasons.

130. Nonzonal Features of Precipitation Distribution. No attempt is made at this point to analyze in detail the features of world rainfall distribution. Such a treatment is deferred until a later part of the book where climatic types and their distribution are considered. It only remains here to point out certain generalizations regarding world precipitation which are associated with nonzonal terrestrial controls (Plate I).

In the low latitudes, especially poleward of latitudes 5° or 10°, there is a marked contrast between the eastern and western sides of the continents in the matter of rainfall. West coasts in the tropics are likely to be dry, or at least much drier than the eastern sides of the continents. This distribution contrast is at least partially explained as follows: (*a*) the eastern side is the windward side while the western is leeward; (*b*) warm ocean currents parallel the eastern sides; cool currents parallel the western sides; (*c*) the tropical air masses at the western side of the subtropical high-pressure cells where upper air lifting is prevalent are usually more unstable than are those at the eastern sides of the cells where there is more upper air subsidence; (*d*) hurricanes are more numerous in the western tropical ocean than they are in the eastern parts.

In the middle latitudes the feature of wet windward coasts and dry leeward coasts is not so striking, except in the case of South America where the continent is relatively narrow. In North America and Eurasia both eastern and western sides of the continents have moderate to abundant precipitation. The eastern sides, even though they are leeward, are kept from being dry as a result of (*a*) the summer indrafts of warm humid tropical maritime air associated with monsoon wind systems and (*b*) the numerous rain-bringing fronts and cyclonic storms which infest the zone of the westerlies. In Eurasia and North America rainfall declines toward the interiors from both the eastern and western sides of the continents, with the deep interiors of both of these land masses becoming genuinely dry. As a rule, the increasingly meager rainfall toward the interiors is more and more concentrated in the warm season.

CHAPTER 6: *Air Masses, Fronts, and Storms*

131. Fronts and Storms as Focal Centers of Precipitation and of Weather Changes. It is a common misconception that air blowing in from the ocean over the land is the immediate and direct cause of rainfall. This is rarely the case except in a minor way, possibly as a result of frictional retardation of the lower air currents with a consequent overrunning and lifting of those aloft. There are plenty of illustrations on the daily weather maps, where air blows in from the sea over flattish land areas with no rainfall resulting. But this is not to say that the land or sea origin of air is of little consequence in affecting the probability of precipitation. On the contrary, it is significant and for the reason that air from over the sea is likely to have a more abundant supply of water vapor and so has greater potentialities for rain.

But actually to cause condensation on a large scale, with resulting precipitation, there is a further requirement than just abundant atmospheric moisture. That requirement is some method of causing a large volume of air to be lifted and consequently cooled. Except where orographic barriers are the cause for ascent, storms are the principal centers of rising air, with the result that storms of various types are the earth's principal generators of precipitation.

A large quantity of moisture in the air is meteorologically significant, not only as a potential reservoir for rainfall, as indicated above, but also because it creates an atmospheric environment conducive to the development and growth of storms. Tremendous amounts of latent energy (heat of condensation) are stored up in the atmosphere's water vapor, where it is available for the production and growth of storms (105). Dry air, therefore, has less potential *storm energy* than humid air. It is especially with rain-producing storms that this chapter deals.

But most of the earth's rain-bringing storms appear to originate along zones of conflict, called fronts, between two unlike air masses. These boundary zones between air masses are the great troughs of horizontal convergence with associated vertical air movement and consequent precipitation. A large share of the weather changes of the earth are linked with the passage of fronts. Because storms, precipitation, and weather changes in general are so closely associated with zones of convergence and their air masses, these interrelationships must be made clear as a preliminary to the discussion of world climates which follows in Sec. B.

Air Masses and Fronts

132. Definitions and Characteristics. An air mass is an extensive portion of the atmosphere whose temperature and humidity characteristics are relatively homogeneous horizontally. Such an air mass develops whenever the atmosphere remains in contact with an extensive and relatively uniform surface for a sufficiently long period for the properties of the air to become similar to those of the surface on which it rests. These extensive and relatively uniform areas of the earth's surface where air masses develop are called *source regions*. Since the primary feature of an air mass is its relative uniformity, it follows that the earth's principal source regions are (*a*) where the surface is relatively uniform and (*b*) where at the same time the wind system is a divergent one. In regions of convergence unlike temperatures are brought close together so that thermal contrasts are great. Anticyclonic circu-

Classification of American Air Masses

Classification by local source regions				General classification after Bergeron (international)	Local air-mass names
Source by		Local source regions	Season of frequent occurrence		
Latitude	Nature				
Polar	Continental	Alaska, Canada and the Arctic	Entire year	cP or cPW, winter cPK, summer	Pc Polar Continental
		Modified in southern and central United States	Entire year	cPK	
	Maritime	North Pacific Ocean	Entire year	mPK, winter mP or mPK, summer	Pp Polar Pacific
		Modified in western and central United States	Entire year	cPW, winter cPK, summer	
		Colder portions of the North Atlantic Ocean	Entire year	mPK, winter mPW, spring and summer	Pa Polar Atlantic
		Modified over warmer portions or the North Atlantic Ocean	Spring and summer	mPK	
Tropical	Continental	Southwestern United States and northern Mexico	Warmer half of year	cTK	Tc Tropical Continental
	Maritime	Gulf of Mexico and Caribbean Sea	Entire year	mTW, winter mTW or mTK, summer	Tg Tropical Gulf
		Modified in the United States or over the North Atlantic Ocean	Entire year	mTW	
		Sargasso Sea (Middle Atlantic)	Entire year	mTW, winter mTW or mTK, summer	Ta Tropical Atlantic
		Modified in the United States or over the North Atlantic Ocean	Entire year	mTW	
		Middle North Pacific Ocean	Entire year	mTW, winter mTW or mTK, summer	Tp Tropical Pacific
		Modified in the United States or over North Pacific Ocean	Entire year	mTW	

Winter Characteristics of Some American Air Masses

Air mass	Station	Weather element	Elevation above sea level				
			Surface	1 km.	2 km.	3 km.	4 km.
cP	Ellendale, N.D.	Temp., °F.	−15	−13	−4	−7	−13
		Sp. humid., g./kg.	0.32	0.35	0.60	0.50	0.45
		Rel. humid., %	82	80	75	63	71
mP (Pacific)	Seattle, Wash.	Temp., °F.	46	32	18	7	−2
		Sp. humid., g./kg.	4.4	2.7	1.5	0.8	0.4
		Rel. humid., %	66	64	64	52	35
mT (Gulf)	Miami, Fla.	Temp., °F.	77	68	55	46	37
		Sp. humid., g./kg.	16.3	13.3	9.8	6.2	5.2
		Rel. humid., %	82	82	83	66	67
mT (Pacific)	San Diego, Calif.	Temp., °F.	68	59	50	43	34
		Sp. humid., g./kg.	11.9	9.8	6.8	4.0	2.1
		Rel. humid., %	86	81	70	51	33

Summer Characteristics of Some American Air Masses

Air mass	Station	Weather element	Elevation above sea level				
			Surface	1 km.	2 km.	3 km.	4 km.
cP	Ellendale, N.D.	Temp., °F.	66	61	50	39	27
		Sp. humid., g./kg.	6.3	5.6	3.9	3.1	2.9
		Rel. humid., %	42	45	43	44	57
mP (Pacific)	Seattle, Wash.	Temp., °F.	63	48	41	34	28
		Sp. humid., g./kg.	7.1	6.3	3.9	2.3	1.7
		Rel. humid., %	62	91	60	42	33
mT (Gulf)	Miami, Fla.	Temp., °F.	75	68	59	48	41
		Sp. humid., g./kg.	17.3	14.9	9.3	6.3	4.3
		Rel. humid., %	93	88	74	58	48
cT	El Paso, Tex.	Temp., °F.	75	81	75	64	
		Sp. humid., g./kg.	11.0	9.7	9.9	7.6	
		Rel. humid., %	52	37	43	43	

and tropical air masses. Air-mass temperature contrasts are strongest along this front, and cyclonic storms are numerous and well developed. Along the high-latitude Arctic frontal zones in each hemisphere the convergence is between two polar air masses, one direct from the polar easterlies and the other somewhat modified polar air along the northern margins of the westerlies. Here the temperature contrasts are smaller than along the polar front and cyclogenesis is weaker. A great majority of the frontal zones follow the sun northward in summer and southward in winter.

A detailed analysis of seasonal air masses and fronts (Figs. 59 and 60) is purposely omitted at this point, for the usefulness of these world charts becomes more evident as the topic of types of climate and their distribution is developed in Sec. B which follows. Only a few of the more obvious facts of distribution are suggested at this time. In both January and July unstable tropical maritime (*mTu*) air masses prevail to the north and south of the intertropical front. Over the tropical continents the heating effect of the land upon these *mT* air masses results in the addition of the symbol *K*. In the latitudes of the subtropical highs the air on the eastern side of each oceanic cell is more stable (*mTs*) than that

on the west (mTu). This is a permanent characteristic of the subtropical highs. It grows out of the fact that there is more subsidence on the eastern side of a subtropical oceanic cell of high pressure than there is on the west. The cool ocean waters on the eastern sides of subtropical oceans further increase the stability of the air.

In the middle and higher latitudes seasonal contrasts in source regions and their air masses are striking. The continents of the Northern Hemisphere in July have a warming influence upon practically all air masses so that the K symbol is prominent. In January on the other hand, these same continents in their northern latitudes are colder than the air (W) so that they exert a stabilizing effect. This is not true, however, in the subtropical sections where the K symbol is present in both summer and winter. Owing to anticyclonic subsidence the air masses over the Northern Hemisphere continents in January are stable (s) while in summer the cyclonic circulation usually makes for instability (u). The mP air masses over the Northern Hemisphere oceans are characteristically warmer than the ocean waters in July (W).

135. North American Air Masses. The North American continent is a region of strong air-mass contrasts. The wide northern part permits the development of severely cold continental air masses in winter, while the lack of east-west relief barriers permits a free flow of polar air southward and of tropical air northward. On the other hand, because of the wide extent of mountains and plateaus in western North America, the entrance of maritime air from the Pacific is made difficult. mP air reaches central and eastern North America only in greatly modified form. In nearly all the above features, North America stands in contrast to Europe.

136. *Polar Continental* (cP) *Air Masses.* The source region for the *winter* cP air in North America is the ice-covered northern interior of Canada, Alaska, and the Arctic Ocean. Its characteristic property is extreme coldness, a ground inversion of temperature, and low absolute and specific humidity ($cPWs$, Figs. 59 and 61). Severe winter cold waves are associated with rapid southward movement of cP air. Marked stability and a strong temperature inversion persist as long as the cP air mass moves southward over a snow-covered surface. Rarely does it become genuinely unstable in the Mississippi Valley before reaching the Gulf of Mexico. Cloudless skies are a distinctive characteristic. Over northeastern United States and the Atlantic Seaboard cP air shows more cloudiness and has somewhat higher surface temperatures (cPu, Figs. 59 and 61). This results from passage over the open water of the Great Lakes in winter and the turbulence produced by the highlands in the eastern part of the country. Because of the general westerly air movement in middle latitudes, as well as the highland barriers, cP air only occasionally reaches the Pacific Coast. When it does, snow and severe subfreezing temperatures result.

Source properties of America cP air in *summer* are markedly different from those in winter. Long days cause the bare snow-free land surface to become much warmed so that the air is heated from the ground (cPK) instead of being chilled from beneath as in winter. A fairly low moisture content, moderately low temperatures, and absence of clouds are characteristic of cP air in summer at or near its source. Precipitation is absent. As it moves southward from its source region, heat and moisture are constantly being added and instability increases. Occasionally modification is so great that thunder showers may develop (Figs. 60 and 61.)

137. *Polar maritime* (mP) *air masses* (*Pacific*) which affect the western parts of North America have as their source region the northern part of the North Pacific Ocean. In winter this region is dominated by the circulation around the Aleutian low. It is surrounded on all sides, except to the south, by cP source regions so that Pacific *winter* mP air was originally very cold and dry cP before it was drawn into the mP source region. Heating and humidifying the cP air at its base changes it from a cold, dry, stable air mass into one which is relatively unstable and whose surface strata, at least, are comparatively mild and humid ($mPKu$, Figs. 59 and 61). The instability (u) is associated with the strongly cyclonic cir-

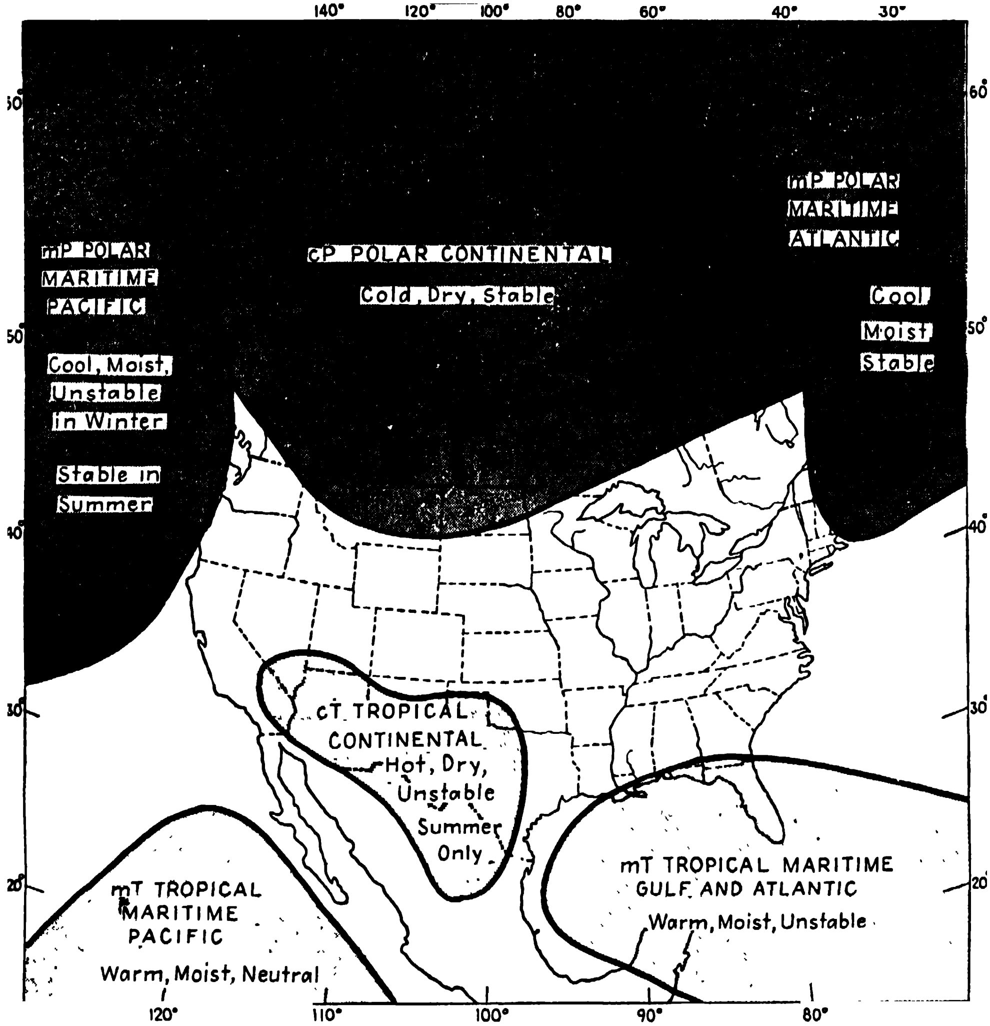


Fig. 61. North American air masses.

culation. As the unstable winter *mP* air advances against the coastal highlands of North America, or the colder air masses near the continent, much cloud and rain result. Important modifications occur as the Pacific *mP* air crosses the western mountains and reaches the interior of the country. By that time it has lost much of its moisture, and its stability has been greatly increased. Some of the finest winter weather east of the Rockies prevails when these Pacific *mP* air masses are in control—moderate winds, clear skies, and relatively moderate temperatures.

In summer the Pacific *mP* source region is geographically identical with what it is in winter. But in the warm season the waters of the North Pacific are colder than the surrounding lands, so that air entering the source region is chilled at the base and made more stable. Most of the eastern Pacific is dominated by the Pacific high in summer, and the strong subsidence in the eastern end of the cell makes for increased stability. The high over the ocean and the low over the continent results in a flow of cool stable *mPs* air southward along the west coast of North America so that clear skies and fair weather are the rule. The stabilizing and aridifying effect is increased as the summer *mP* passes over the cold water which upwells along the

coast of California. In general summer mP air at Seattle is more stable then cP air in the Upper Mississippi Valley.

138. *Polar maritime* (mP) *air masses* (*Atlantic*) which originate over the cool Atlantic waters between Cape Cod and Newfoundland were originally cP air which moved off the continent and were modified over the cold waters. Owing to the prevailing west-east air movement the North Atlantic is not an important source region for air masses affecting North America. This is especially true in winter. Seldom does Atlantic mP air extend its effect beyond the Appalachians. In *winter* Atlantic mP air is characteristically dry and stable aloft, while the surface layer is moderately unstable, moist, and chilly rather than cold. As compared with Pacific mP air, its lower levels are colder, drier, and more stable. As Atlantic mP air comes onshore in winter it results in weather with surface temperatures near freezing, high relative humidity, low visibility, and frequently light flurries of fine mist (Fig. 61).

Atlantic mP air masses have their greatest influence upon American weather in late *spring* and early *summer*. At that time of year the North Atlantic waters are abnormally cold compared with the adjacent continent so that they become a source region of genuinely cold air for the whole coastal area east of the Appalachians and north of Cape Hatteras. Atlantic mP summer air is distinctly cool, relatively stable, and shows only thin and broken clouds from which precipitation never falls.

139. *Tropical maritime* (mT) *air masses* (*Gulf and Atlantic*) which affect eastern United States have their origin over the warm waters of the Gulf of Mexico and the Caribbean Sea or over the Sargasso Sea of the Atlantic proper. Gulf and Atlantic mT air at its source is characterized by marked warmth and high moisture content at lower levels. In *winter* as the mT air moves inland and poleward from the Gulf of Mexico, the ground strata are cooled and stabilized by contact with a colder earth, and where air movement is slight dense fog frequently is the result. In rather strong air currents dense mist or fine drizzle is likely (Fig. 61). Convective precipitation rarely occurs within this mT air mass in the cool season, but along a front, where it is forced to ascend, precipitation may be extremely heavy. Combined with warmth and high humidity there is likely to be considerable cloudiness of the low stratus type, especially during the night and early morning.

Because of prevailing sea-to-land pressure gradients over eastern United States in *summer*, Gulf mT air is able to extend much farther into the interior of the continent at that season than in winter. It is responsible for the oppressive humid heat which characterizes the summer weather of much of central and eastern United States. As it leaves its source region summer Gulf mT air is somewhat warmer and more humid than it is in winter. Moving in over the continent and continuing northward over the warm land, there is a tendency for its surface layers to increase in temperature and therefore in instability ($mTKu$). Midday instability with numerous widely scattered local thunderstorms is characteristic of the air mass. Gulf mT air is the principal source of precipitation for the North American region east of the Rockies.

140. *Tropical maritime* (mT) *air masses* (*Pacific*) which affect western United States have their origin in the subtropical latitudes of the eastern North Pacific Ocean. Because of the relatively cool ocean surface in this source region Pacific mT air in *winter* is only moderately warm, or even cool, at least near the ground. The prevailing anticyclonic circulation further increases the stability (mTs). Water-vapor content may be moderately high in the surface strata but certainly far from great, considering that its source region is a tropical ocean. Clouds are absent until the Pacific mT air has moved some distance northward from its source and surface cooling has resulted. On the other hand, heavy winter rains along the Pacific Coast and as far inland as the Great Basin or the southern Plateau may result when Pacific mT air is forced to overrun colder air masses. When cold air masses are absent, Tp air may sweep poleward along the Pacific Coast as far as Seattle or beyond with little or no rain.

During *summer* mT air masses play a very

minor part in Pacific Coast weather, *mP* air certainly dominating the situation as far south as southern California.

141. *Tropical continental (cT) air masses* play an insignificant role in North American weather. Chiefly this is due to the fact that North America lacks an extensive land area in subtropical latitudes. Only a relatively small area in southwestern United States and northwestern Mexico develops *cT* air, and moreover this occurs only in the warm season. During summer, as a result of strong insolation heating, the air in this source region becomes excessively hot and dry. As it moves eastward from the region of origin its influence is felt on the Great Plains, but as it moves farther eastward it mixes with other air masses and its identity is gradually lost. *cT* does not appear on the daily weather map east of the Mississippi River.

142. Eurasian Air Masses. *Europe*, excluding Soviet Russia, is lacking in a genuine source region. It is, rather, a transition zone where invading air masses are modified and transformed. The air masses which control the weather of western Europe are, in many respects, similar to those of western North America. Polar maritime air (*mP*), which plays such an important role in Europe's weather, resembles closely Pacific *mP* air in western maritime Canada and the United States. In *winter* it enters Europe as a fairly mild humid air mass of varying degrees of instability, depending on its route across the Atlantic. When caused to rise along fronts or over relief barriers, it yields plentiful precipitation. As it moves inland from the coast and is chilled at the base, its stability is increased. In *summer* the *mP* air is more stable, but as it moves slowly toward the interior it is warmed at the base and becomes increasingly unstable, so that cumulus clouds and convectional showers are fairly common (Figs. 59 and 60).

Tropical maritime (*mT*) air in western Europe resembles Pacific *mT* air in western North America, but it is cooler, drier, and more stable than Gulf *mT* air in southeastern United States. *Winter mT* air in western Europe has originated on the northern and eastern flanks of the Atlantic subtropical high and has traveled a northerly route over increasingly cooler waters. It is, therefore, relatively stable. It is warmer and moister than polar air, to be sure, but because of its stability it yields abundant rain only if lifted by relief barriers or along frontal surfaces. *Summer mT* is not common in Europe north of latitude 40°N. South of 40°N., it is a very stable (*mTs*) air mass.

Polar continental (*cP*) air masses are relatively infrequent in western Europe but become increasingly more prevalent in central and eastern Europe. The general west-east atmospheric circulation in middle latitudes makes westward thrusts of *cP* air difficult. The source region for this cold air is snow-covered Soviet Russia and Finland. European *winter cP* at its source resembles *cP* in Canada—low temperatures, with a surface inversion, low humidities, and a high degree of stability. By the time *cP* has reached central and western Europe it has been considerably modified, especially by relief barriers. Severe cold waves such as those common to the open Mississippi Valley are unlikely. *cP* air in the region of the Rhineland has a surface temperature of about 20°F. *Summer cP* is confined to northern Europe where it is a relatively cool, dry air mass.

143. *The Mediterranean Borderlands* in *winter* are a region of air-mass convergence, there being a relatively strong front developed over the warm waters of the Mediterranean Sea in the cool season. *mP* and *cP* air from Europe and *cT* from northern Africa enter the basin and are there modified in temperature and humidity. General instability and associated cyclonic storms with cloud and rain are the results. In *summer* the Mediterranean is a region of anticyclonic circulation and prevailingly warm, dry, stable *cT* air masses. Rainfall is consequently meager (Figs. 59 and 60).

144. *Eastern Asia* in its air-mass characteristics resembles eastern North America. In *winter* polar continental (*cP*) air from the extensive source region of the great Siberian anticyclone dominates the weather of central and eastern Asia. At its source this air is colder and drier then North American *cP*. As it surges southeastward from its source, it encounters rough

terrain with the result that it is considerably modified before it descends to the plains of China and regions farther south, even into the tropics. India is largely protected from invasions of Siberian *cP* by the high mountain and plateau barriers bordering it to the north. North of about the Yangtze River *cP* so dominates the weather that winter precipitation is very meager. Southward, however, contact with *mT* air is more frequent, and as a result winters are much cloudier and rainier. *cP* that reaches Japan has been warmed, humidified, and made somewhat unstable by its passage over the Sea of Japan. When this air is forced aloft over the mountains of western Japan, it precipitates heavily in the form of snow. *cP* air in *summer* is of minor importance: for the most part it is confined to northern interior Siberia (Figs. 59 and 60).

Tropical maritime (*mT*) air masses dominate the weather of eastern and southern Asia in *summer*. This air closely resembles Gulf *mT* in that it is warm, moist, and unstable. As it moves inland over the warm lands its instability is further increased and heavy convective, frontal, and orographic rain results. Because of the anticyclonic circulation and the prevalence of polar air in *winter*, *mT* air has much greater difficulty entering eastern and southern Asia in the cool season. When it does invade, it makes fronts with *cP* resulting in cloud and rain. *cT* air is widespread in southern interior Asia in summer.

145. South America in the low latitudes is dominated by warm unstable *mT* air masses pretty much in all seasons. In January the I.T.F. migrates far southward over the heated continent and *mT* air is drawn into this convergence, with the result that heavy high-sun rainfall prevails over almost all of Brazil south of the equator. In the latitudes of the subtropical high-pressure cells there is a marked contrast between the cooler stable air (*mTs*) along the western side of the continent and the unstable *mTu* air on the Atlantic side. This contrast is reflected in the aridity on the Pacific side and the abundant rainfall on the east coast. Polar maritime (*mP*) air prevails over the southern part of the continent. Storms which develop along the front formed between the *mP* and *mT* air masses are responsible for a large part of the precipitation which falls in the middle latitudes of South America (Figs. 59 and 60).

146. Africa in its broad northern part is a source region for tropical continental (*cT*) air in all seasons. This is the region of the Sahara. *mT* air prevails throughout the equatorial parts of the continent. In the Southern Hemisphere subtropics there are the same air-mass and rainfall contrasts between east and west coasts as were pointed out for South America. Only the very southern extremity of Africa feels in winter the influence of *mP* air and of the storms which develop along the front between *mP* and *mT*.

147. Like northern Africa, central *Australia* is a source region for *cT* air at all seasons. In summer (January) the southward migration of the I.T.F. causes northernmost Australia to feel the effects of warm unstable *mT* air with a resultant rainy season. Subtropical east and west coasts have the same air mass and rainfall contrasts as were described for Southern Hemisphere South America and Africa. Like southernmost Africa, the southern extremities of Australia, in winter, feel the influence of *mP* air and of polar-front cyclonic storms.

Moving[1] Cyclones and Anticyclones

148. Classes of Cyclones and Anticyclones. The terms cyclone and anticyclone are applied to a variety of storms of contrasting types and characteristic locations. Thus there are (*a*) nonviolent cyclones and anticyclones of the intermediate zones, characteristic particularly of the cooler seasons. In fact they are so prevalent in the middle latitudes that the "prevailing" westerly winds are scarcely obvious on the daily weather maps. More commonly the surface winds appear to be converging and diverging circulations around distinct low- and high-pressure centers, these being, respectively, cyclones and anticyclones. It is analogous to a river being so full of eddies and whirlpools that it is difficult

[1] This title is employed in order to distinguish the storms here described from the stationary, semipermanent centers of high and low pressure, also designated as cyclones and anticyclones.

to detect the direction of the main current. These characteristically mild storms of the middle latitudes stand out by contrast with (*b*) the smaller, but more intense, cyclones (hurricanes and typhoons) of tropical latitudes, the latter storms commonly being violent and destructive. In addition to these severe storms of the tropics there are, also, (*c*) in the low latitudes many weak, slow-moving cyclones which produce heavy rainfall but which are usually associated with only weak winds. This last type of cyclone likewise occurs in certain subtropical parts of the middle latitudes during the warm season. Each of the three types noted above is an important element of weather and climate in those parts of the earth where it is characteristic. At least the first type is important in producing temperature conditions and changes, but no doubt the chief climatic significance of moving cyclones as a class of storms is that within them great masses of air are forced to rise, resulting in precipitation.

MIDDLE-LATITUDE CYCLONES AND ANTICYCLONES

General Characteristics

149. Of principal importance in producing the frequent, erratic, and nonperiodic weather changes so characteristic of middle latitudes are the moving cyclones and anticyclones which fill the westerly wind belt. In such regions the fickleness of the weather is proverbial, and it is in these parts of the world that weather-forecasting services are most necessary and best developed. No two storms are exactly alike, so that the generalizations concerning cyclones and anticyclones which follow must not be expected to fit any particular storm in all respects. Moreover, they differ somewhat from region to region.

150. Nature and Location. Cyclones are low-pressure storms and commonly go by the name of *lows*, or *depressions*, while anticyclones are high-pressure areas and are called *highs*. The cyclone must, therefore, be a mass of light air since surface pressures are low, while, conversely, the anticyclone, or high, is a mass of heavier air. Since these storms develop as a result of air-mass conflict in the middle-latitude zones of convergence, they are characteristic features of the westerly wind belts and are best known, therefore, between latitudes 35° and 65° in each hemisphere. Because cyclones and anticyclones are traveling storms within the westerlies, it is expected that they will be carried by those winds in general from west to east, much in the same way that a whirlpool in a river is carried downstream by the main current.

151. Appearance. As one sees these storms on the published United States weather map they are represented by a series of closed, concentric isobars, roughly circular or oval in shape (Figs. 62 and 63). In the cyclone the lowest pressure is at the center, and it *increases* toward the margins; in the anticyclone, pressure is highest at the center and *decreases* outward. If the isobars in a low are imagined to be contours, then the cyclone resembles a circular or oval depression, while the high has the appearance of a dome-shaped hill. There is no definite amount of pressure that distinguishes lows from highs; it is entirely a relative thing. Normally there are 10 to 20 millibars, or several tenths of an inch, pressure difference between the center and circumference of a low. Occasionally a large and particularly well-developed winter cyclone may show a difference of as much as 35 millibars, or 1 in. In highs the pressure difference between center and margins is usually in the neighborhood of 17 millibars, or $\frac{1}{2}$ in., although it may be double that in some instances. It is a general rule that both cyclones and anticyclones are less well developed, have smaller differences in pressure, have weaker pressure gradients, and travel at lower speeds in summer than in winter.

152. Size. There are great variations in the size of these storms, but on the whole they spread over extensive areas, sometimes covering as much as one-third of the United States, or 1 million square miles, although most of them are smaller. They are *extensive* rather than *intensive*. Thus a normal cyclone with a vertical thickness of 6 to 7 miles probably will have a diameter of one hundred times as great. Cyclones are inclined to be elliptical or egg-shaped in contour, with the

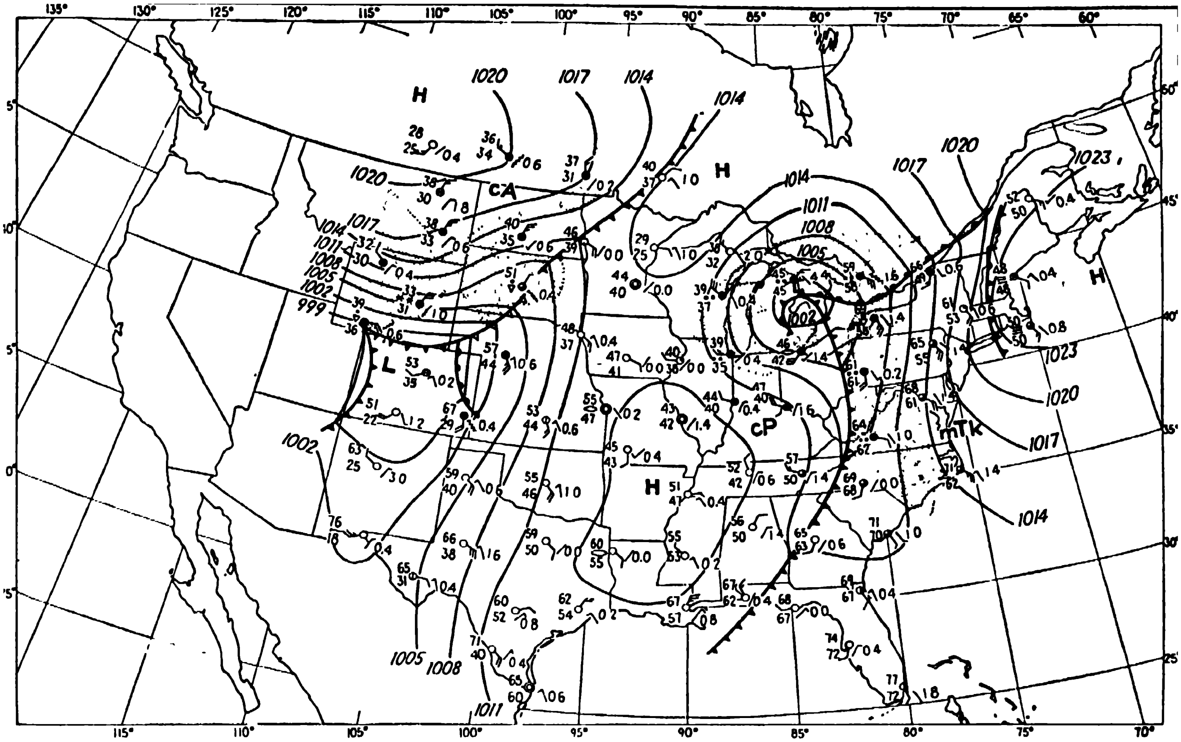


Fig. 66*B*. Synoptic weather chart for 0030 C.S.T., May 16, 1942.

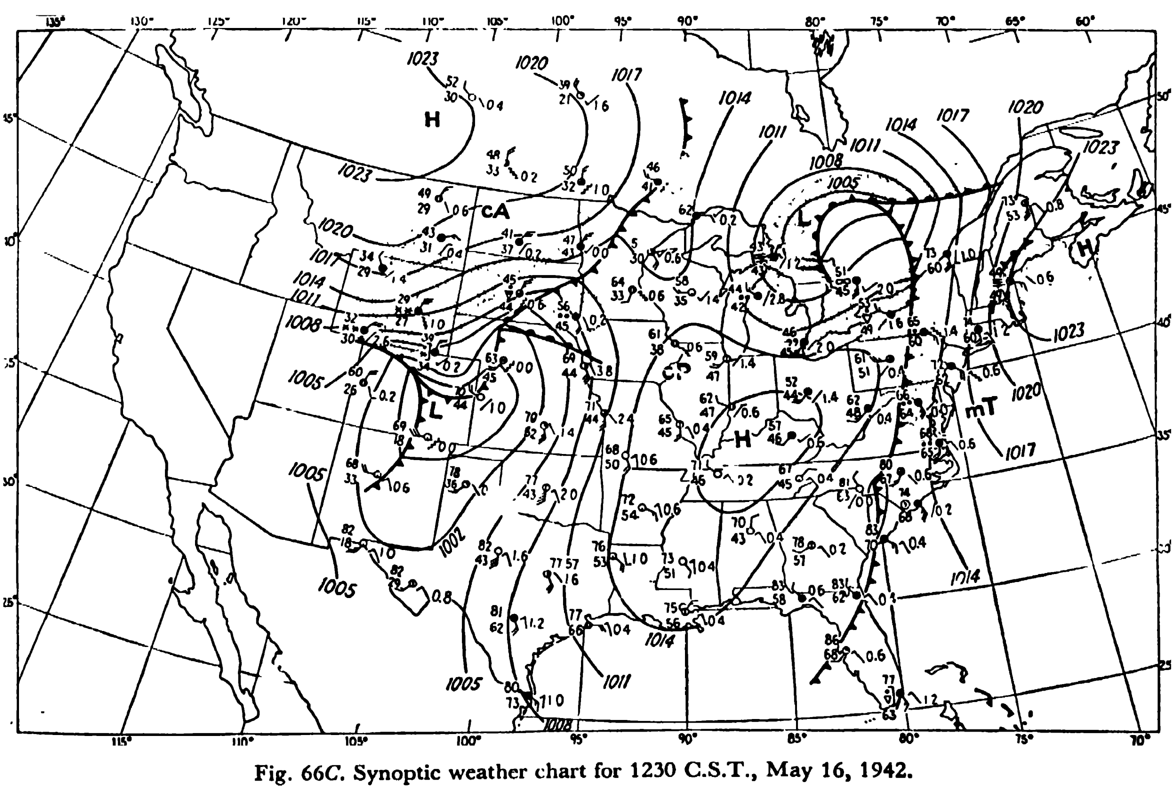


Fig. 66*C*. Synoptic weather chart for 1230 C.S.T., May 16, 1942.

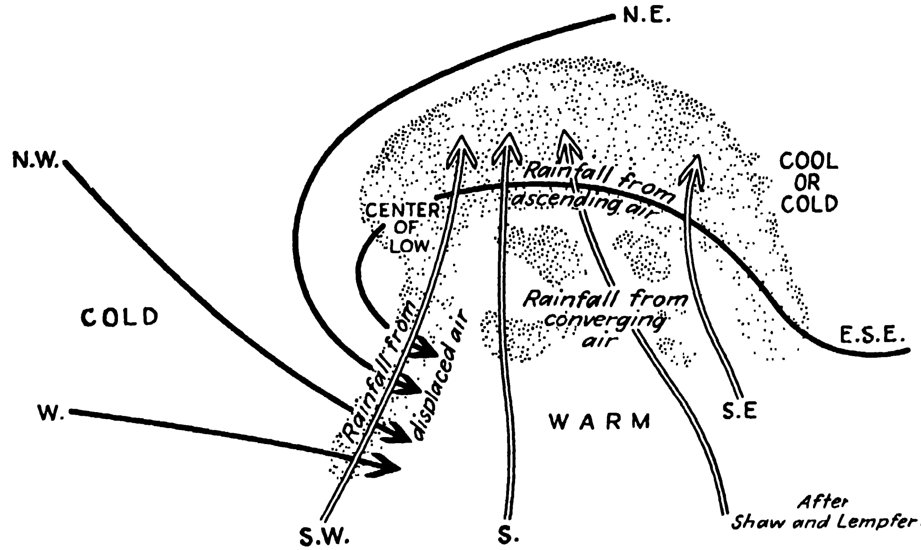


Fig. 67. Representation of the wind system and precipitation areas (stippled) in a middle-latitude cyclone.

toward the center of the storm in a counterclockwise whirl. But the simple inward-spiraling cyclonic wind system (Fig. 62) described above and observable on the weather map is a partial illusion. This comes about as a result of the fact that the weather map is a snapshot of atmospheric conditions at a particular instant so that the storms are shown as stationary phenomena, when in reality they usually are moving at the rate of several hundred miles a day. The *moving cyclone's* actual wind system is more accurately, although still very diagrammatically, represented by Fig. 67. In it convergence of air flow still is conspicuous, but the simple in-spiraling system is considerably modified. Most significant is the fact that to the south, southeast, and possibly southwest of the storm center are southerly winds, usually of subtropical or tropical origin, while to the west, north, and northeast are colder air masses which had their origin in higher latitudes.

As a result of the converging system of air flow about a cyclonic center, winds on the front (east, or direction storm is traveling) of such a storm are from a general easterly direction, some of it northeasterly, more of it from the southeast and south. On the rear (west) of the storm, winds are, in general, westerly and especially from the northwest (Fig. 67). The easterly winds on the front of a low are likely to be both tropical and polar in origin, since the front separating the two air masses extends roughly eastward from the storm center. In central and eastern United States the southerly winds *south* and *west* of the front are from the Gulf and tropical Atlantic and so are warm and humid. On the other hand the northeast, east, or even southeast winds *north* and *east* of the line of discontinuity are of polar origin and consequently drier and colder. From wind direction alone it is unsafe to generalize as to whether an air mass is of polar or tropical origin, for the polar air on the front of a cyclone is not uncommonly observed as a southeast current. This is polar air that has been modified by a relatively long journey over middle latitudes and is returning poleward on the rear of a retreating anticyclone.

It is obvious that all these easterly winds on the front of a cyclone are opposite in direction to the general current of westerly winds in which they exist and likewise opposite to the direction of storm movement. Thus while the storm travels from west to east, the winds on its front blow from east to west. This characteristic of a cyclone, which in many respects is an eddy or whirlpool of air in the westerlies, finds a counterpart in the whirlpool of a river. The whirlpool of water is carried downstream by the major current just as the storm is carried eastward by the westerlies, but on its downstream side the water flows into the whirl in a direction opposite to that of the general current and likewise

opposite to the downstream movement of the whirlpool itself. It is evident, then, that a cyclone is the meeting place of two very contrasting masses of air: a colder, drier, and heavier one arriving from higher latitudes on the poleward and rear sides of the storm; and a milder, more humid one from lower latitudes on the equatorward and front side (Fig. 66).

156. Wind Shift with the Passing of a Cyclone. When a cyclonic center approaches and passes by an observer, the latter will experience general easterly winds as long as the low center is to the west of him, in other words, as long as he is on the front of the storm. As the center passes by, leaving him in the western, or rear, half of the low, the winds shift to the west. Easterly winds, therefore, often indicate the approach of a cyclone with its accompanying rain and cloud, while westerly winds more often foretell the retreat of the storm center and the coming of clearing weather.

In many cyclones this shift from easterly to westerly winds is rather gradual and lacking in abruptness. In storms with a marked equatorward elongation, so that the isobars are roughly in the form of the letter V, the wind shift is likely to be abrupt (Fig. 80). Along the windshift line, which is approximately a line joining the apexes of the V-shaped isobars south of the center, winds of contrasting temperature, humidity, and density meet at a sharp angle, and violent storms and turbulent weather conditions often are the result. This wind-shift line is the cold front described in Art. 179*b*.

157. *Veering and Backing Winds.* If the center of a cyclone passes to the north of the observer, so that he is in the southern quadrants of the storm, the succession of winds experienced will be southeast, south, southwest, and finally west and northwest (Figs. 62 and 67). This is called a *veering wind shift*. On the other hand, if the storm center passes south of the observer, so that he is on the north side of the cyclone, he will experience in succession northeast, north, and finally northwest winds. This is known as a *backing wind shift*. The following note regarding *wind-barometer indications* associated with a passing cyclone formerly appeared on the United States daily weather map.

When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hr. with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hr. with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

158. Wind System of an Anticyclone. The term anticyclone was invented to designate the outflowing, or diverging, system of winds about a center of high pressure (Fig. 63). Deflection due to earth rotation causes the outflow of air about a high to develop something of a clockwise whirl (Northern Hemisphere). Since surface air in the high is constantly spreading outward from the center, it follows that there must be a compensatory feeding in of air at higher elevations, and subsequent settling of it, in order to maintain the high. This characteristic subsidence in anticyclones causes the air in such circulations to be stable. The wind systems about highs and lows, therefore, are opposite (*a*) in direction of gradient-induced flow, (*b*) in direction of spiral deflection, and (*c*) in vertical movement at the centers.

Anticyclonic wind systems are usually less well developed than those of cyclones so that no characteristic wind shift is forecast as they pass by. In general, however, winds on the front (east) of an advancing high are westerly, while those on the rear are easterly. Since lows and highs often alternate with one another as they move across the country, it is evident that the westerly winds on the front of a high and the rear of a low have a similar origin and are much alike in character. Pressure gradients are usually less steep and wind velocities lower in anticyclones than in cyclones. Weak pressure gradients are particularly conspicuous toward the centers of highs where there is much light wind and calm. The strongest winds are likely to be found on the front margins of advancing highs where there is a merging with the pre-

ceding low. In this location between the cyclonic and anticyclonic systems the isobars tend to become nearly parallel straight lines trending in a general north-south direction. A strong horizontal pressure gradient from west to east is thereby developed, which is a consequence of combined westerly-wind gradients and storm gradients, vigorous west and northwest winds being the result. Cold waves and blizzards over central and eastern North America are associated with these strong outpourings of cold air in the transition areas between the rears of lows and the fronts of highs.

PRECIPITATION IN CYCLONES AND ANTICYCLONES

159. Cyclones and Anticyclones Opposite in Precipitation Characteristics. As a general rule, conditions in cyclones are conducive to condensation, so that commonly they are accompanied by large areas of cloud and often precipitation as well. Not every cyclone, to be sure, is associated with rainfall, but on the other hand many of them are. Anticyclones, still maintaining their opposite nature in precipitation as well as in pressure and winds, are inclined to be fair-weather areas with clouds much less prevalent and rainfall meager. These differences are not unexpected, since in lows there is a general convergence of contrasting air currents toward the center of the storm with a consequent development of fronts. Lifting of the converging air masses, and subsequent cooling due to expansion, is the result. On the other hand, the slowly settling and warming air in anticyclones, as well as the diverging character of the surface air currents, is distinctly antagonistic to cloud and rainfall. The diverging nature of the anticyclone's air makes a conflict of contrasting air masses unlikely, so that active fronts are not to be expected.

160. Cyclonic Precipitation. Most of the cool-season precipitation of lowlands in the middle latitudes is cyclonic in origin. Winter snowfall on plains in these latitudes is almost exclusively from cyclonic storms. The fewer and weaker lows of the warmer months yield a smaller percentage of that period's rainfall, since in summer convection and thunderstorms are likely to be more prevalent. Although cyclonic rain is the result of rising air, normally it does not rise because of local heating but rather because of forced ascent resulting from (*a*) a convergence of great masses of air toward a center, (*b*) the underrunning and lifting of warmer and lighter air masses by cooler heavier ones, and (*c*) the ascent of warm currents over colder ones (Figs. 66 and 67). Unlike conditions in a thunderstorm, where rapid vertical ascent is characteristic, the lifting of air in cyclones, as noted earlier (154), is more often a gliding of warm, moist air up a mild slope formed by the upper surface of a colder, denser mass of air. Cooling is slower in the latter case, and rainfall less heavy. Cyclonic precipitation, therefore, inclines toward being light or moderate in rate of fall, but because of the greater areal extent of the storm it is of relatively longer duration than that of thunderstorms. Dull, gray, uniformly overcast skies, with steady precipitation, are typical of cyclonic weather. It should be stressed that precipitation in any storm would be minor in amount and of short duration if it were not that new supplies of water vapor are constantly being imported by winds to any area where rain is falling.

Neither the expectancy of precipitation nor its nature and origin are the same in all parts of a low. In general, the front or eastern half is more cloudy and rainy than is the rear or western half, although the latter is not completely lacking in precipitation. Clouds and rain extend out much farther to the front or east of the center than to the rear or west. This is because the warm air currents, from which the precipitation is derived, are moving eastward. As a consequence they overrun the cold air along the warm front much farther to the east of the storm center than they do to the west. In well-developed winter lows snow is more common in the cooler northeastern part, whereas rain occurs more frequently in the warmer southeastern quadrant. Heavy snows over the eastern part of the United States usually arrive when storms travel the more southerly routes,

so that the central and northern states are on the poleward sides of the cyclones.

161. Regions of Precipitation within a Cyclone. Three general regions of precipitation within a low may be distinguished. As a general rule the rain areas are associated with vertical displacement of mild and humid maritime air masses, often of tropical origin. The cold air masses act chiefly as barriers over which the warmer air is lifted, and only a small amount of precipitation is actually derived from the cold air itself (Figs. 66 and 67).

a. Rainfall from Converging Air (Nonfrontal). In the southeastern quadrant of the storm, in particular, the warm, humid, southerly (including southeasterly and southwesterly) currents are driven upward by their own convergence as they move toward the center of the low (Figs. 66 and 67). This section of the cyclone is not a region of prevailing heavy cloud cover and persistent rain. Quite the contrary, for, although scattered showers are common and widespread, there also may be considerable broken sky and sunshine. During the warm season, the sultry, humid section to the south and southeast of the low center is a region of active convection, with cumulus clouds and local thunderstorms.

b. Warm-front Rain. To the north, northeast, and east of the storm center the warm, humid, southerly air masses meet the colder, drier air of polar origin. Because the latter is more dense, the warm air flows up over the gently inclined wedge of colder air just as it would flow over a mountain range and is lifted above the earth's surface (Fig. 58). As a result of rising over the wedge of cold air, the southerly currents are cooled by expansion, and widespread cloud and precipitation are the result (Figs. 64*e* and 67). Chilly, gray, overcast days with long-continued steady rain are typical of weather in this part of the storm. In the colder months this is also the region of heavy snowfall. Since the warm air is rising over the cold wedge along a gently inclined plane whose angle of slope is between 0.5 and 2°, its increase in elevation is slow, so that the resulting precipitation is likely to be only light or moderate in rate of fall, although, because of its long duration, the total amount may be considerable. It is not uncommon for warm-front rains to continue steadily for 24 hr. and more without letup. Such moderate rain is ideal in some respects, for it comes slowly enough for the ground to absorb most of it, and surface runoff and destructive slope wash and gullying are reduced to a minimum. Low evaporation under such conditions of weather likewise increases the effectiveness of the precipitation. In the warm seasons if the air ascending over the cold wedge is conditionally unstable, warm-front rainfall may be relatively heavy. Cool, overcast weather with rain is ideal for the growth of forage crops and pasture but less so for a crop like corn, which benefits from sunshine and higher temperatures. It needs to be kept in mind that it is not from the cold surface air that the rain is chiefly coming but rather from the southerly currents aloft which are rising over the cold northerly air. Precipitation falling through the cold surface air, however, has its temperature reduced so that it reaches the earth as a chilly rain, and the day is inclined to be dark and dismal.

c. Cold-front Rain. To the south and southwest of the storm center is still another region of forced ascent. Here the cold west and northwest currents of polar origin meet and underrun the warm southerly currents, forcing them upward, sometimes with much vigor (Figs. 58, 64*e*, and 67). This cold-front rain belt is best developed in storms with a marked southward looping of the isobars, *i.e.*, a V-shaped cyclone, for under these conditions the contrasting air masses meet at a sharp angle with resulting vigorous overturning. In storms with more circular shape this is less likely to be the case. The name *squall line* has been derived from the fact that it may be a region of great atmospheric turbulence, with associated severe thunderstorms and squall winds. Because of the rapid lifting and overturning of the warm air along the cold front, the accompanying rain is likely to be in the form of heavy showers but not of long duration. This cloud and rain belt, therefore, usually is much narrower than that along the warm front to the north and east of the storm center.

It should be stressed here that not all these

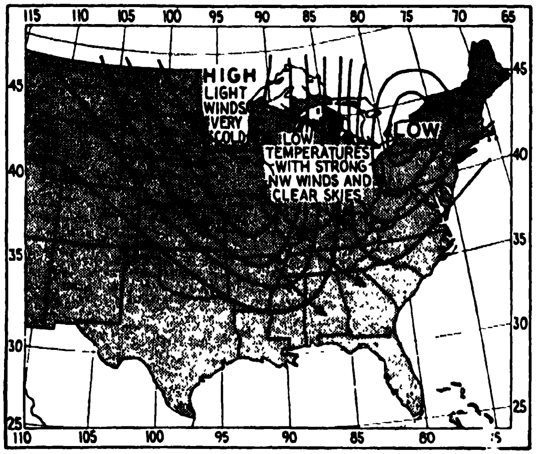


Fig. 68. A winter anticyclone advancing southward as a mass of cold polar air.

three rainfall types or areas are present in each storm, nor are they always distinct from each other. There are numerous mergings, modifications, and intermediate conditions. Nevertheless, all three types are sufficiently common and distinct in cyclones to warrant their recognition.

TEMPERATURE IN CYCLONES AND ANTICYCLONES

162. It is difficult to make significant generalizations regarding temperature contrasts between lows and highs. It is not true, as is sometimes stated to be the case, that, disregarding the season of the year, cyclones are always areas of high temperature and anticyclones of low. In themselves they are neither hot nor cold, but, depending upon the season as well as their own individual character (region of origin, path, velocity of movement), they may be either or both. An analysis of temperatures in cyclones and anticyclones actually resolves itself into a study of the air masses that comprise the storms.

163. Temperatures in Anticyclones. Certainly in the winter season a vigorous, well-developed high, advancing rapidly toward central and eastern United States from northern Canada, or from Arctic Russia toward central and western Europe, progresses as a mass of cold, dry, polar continental air with clear skies. Such an anticyclone accounts for the *cold waves* and bitterest winter weather (Figs. 68 and 69). This type of high is cold for two reasons: (*a*) because it advances southward from the Arctic regions as a mass of cold polar air accompanied by strong northwest winds and (*b*) because its dry, clear air provides ideal conditions for rapid terrestrial radiation during long winter nights. An anticyclone composed of *mP* instead of *cP* air, either in North America or Europe, brings less severe cold. Even in summer, a well-developed high approaching rapidly from higher latitudes gives low temperatures for the season, providing several days of clear, cool, delightful weather. It is not unusual in middle latitudes, then, for highs to have come to be associated with low temperatures for any particular season.

However, when in summer a large, relatively stagnant high, composed of tropical or subtropical air, spreads slowly over the south-central part of the country, excessively high temperatures, called *hot waves*, are likely to result over central and eastern United States (Fig. 70). The same clear skies and dry air that make for rapid terrestrial radiation during the long winter nights are conducive to maximum receipts of strong solar radiation during long summer days. Moreover, as tropical air from this anticyclone moves northward over the country, the south winds carry with them the heat absorbed in the lower latitudes. Clear, mild days in the cooler seasons likewise are usually associated with these same large, stagnant highs over the south-central part of the country. In summary, then, it may be stated that vigorous, moving highs arriving from higher latitudes are likely to bring lower than normal temperatures, especially in winter; while weak, stagnant highs in summer, especially in the lower middle latitudes and in the subtropics and tropics, are associated with abnormally high daytime temperatures. Large diurnal temperature variations are characteristic, because of the dry air and the general absence of clouds.

164. Temperatures in Cyclones. Well-developed cyclones, accompanied by extensive cloud cover and precipitation, are likely to bring higher than average temperatures in

winter and somewhat lower than average temperatures in summer— just the opposite from those induced by the anticyclone. During the long winter nights the cloud cover and humid air of the cyclone tend to prevent rapid loss of earth heat, while these same conditions in summer, when days are long and sun stronger, tend to weaken incoming solar radiation.

165. *Temperature Contrasts within Different Parts of a Cyclone.* The foregoing general rule concerning lows and seasonal temperatures cannot be accepted too literally, however, for a cyclone, composed of unlike air masses, usually has marked temperature contrasts within its several parts or quadrants. Thus the south and southeast part (front) of a low, where relatively warm air masses and southerly winds prevail, is considerably warmer than the north and west portion (rear), where air movement is from cooler higher latitudes. The effect of these air-mass temperature importations is to cause the isotherms in cyclones to trend north-northeast by south-southwest instead of the usual east-west direction, the south winds on the front of the storm pushing them poleward, and the northwest winds on the rear pushing them equatorward (Figs. 66 and 71). To the east and north of the storm center, where the air is of a modified polar character, being markedly colder than the tropical air to the south but not so severe as the fresh polar air to the west, isotherms more closely follow the parallels.

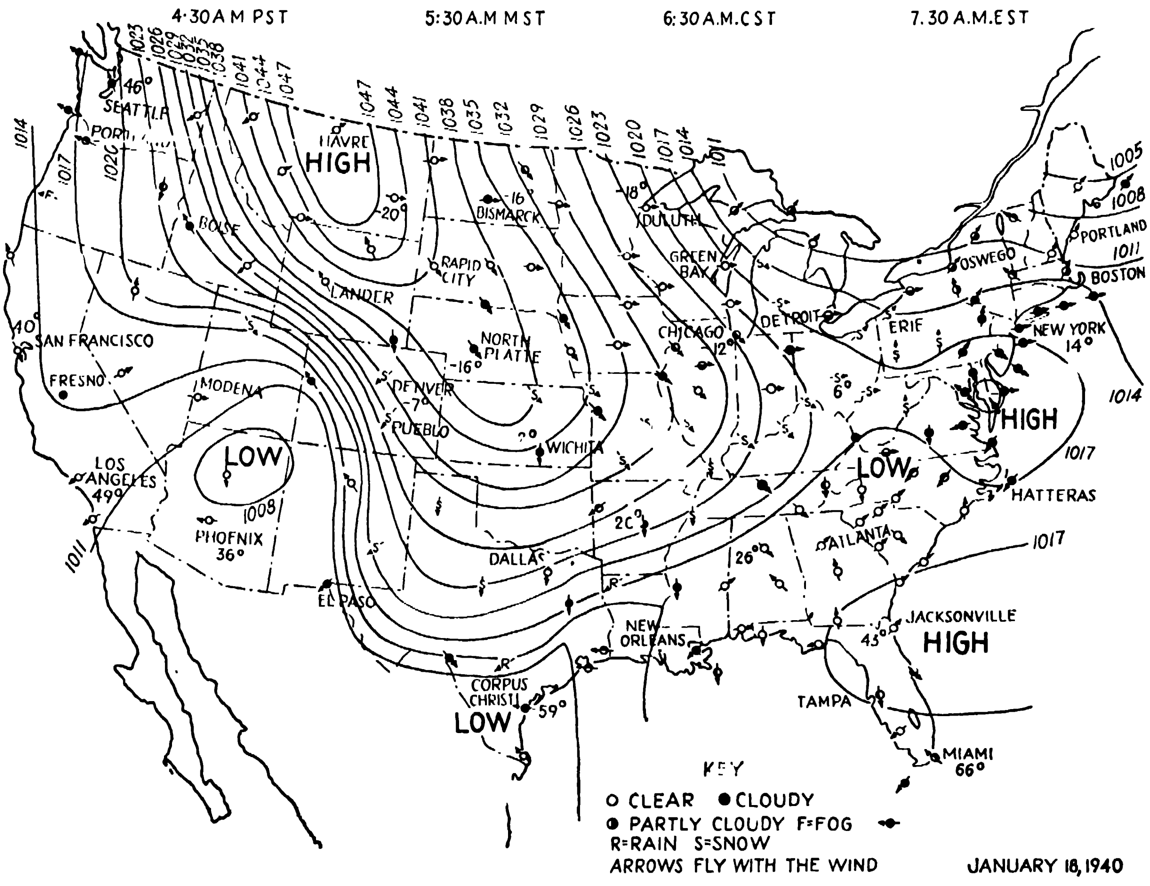


Fig. 69. United States daily weather map. A great polar continental (cP) air mass had advanced into the United States as a high-pressure system from the arctic plains of Canada. St. Joseph, Mo., had a minimum temperature of 21° below zero, and Galveston, Tex., on the Gulf of Mexico, 15° above zero. Ten inches of snow fell at Birmingham, Ala., and at Atlanta, Ga. (*Courtesy U.S. Weather Bureau.*)

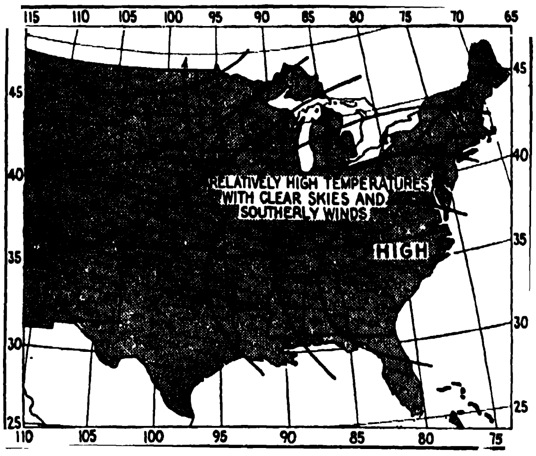


Fig. 70. A relatively stagnant anticyclone over southeastern United States producing unseasonably warm weather over the central and eastern parts of the country.

In general, the average rise of temperature above seasonal normal in front of a winter storm in eastern United States is not far from 10° although it may reach 20 or 30°. Between the front and rear of a well-developed winter cyclone in eastern United States the temperatures may differ by as much as 30 to 40° or even more. If the temperature of the center of a low is taken as a standard, the average departures of the four quadrants of well-developed winter cyclones in eastern United States are as follows: northwest, −8.7°; northeast, −5.6°, southeast, +6.3°; southwest, +2.6° (Ward). Stations on the southern side of a passing low, therefore, experience a greater *change* in temperature than do those to the north of the center, even though the temperatures are not so low.

In western Europe the temperature contrasts are not so great as they are in North America east of the Rockies. Europe has no such excellent source region for warm, humid tropical air masses as is the Gulf of Mexico for the United States so that the warm sectors of her cyclones do not have such high temperatures as those of eastern North America. Moreover, a large number of European storms have already reached the occluded stage by the time they enter the continent so that there may be an absence of tropical air at the surface.

166. Summary of Weather Changes with the Passing of a Well-developed Cyclone and a Following Anticyclone over Eastern United States. The essence of cyclonic control in weather is its irregularity and undependability. Averages of the weather elements by days, months, or years give only a lifeless picture of the actual weather experienced, for such averages tend to mask the nonperiodic storm control. Rapid and marked weather changes are characteristic of regions and seasons where cyclones and anticyclones are numerous and well developed, as they are, for instance, over eastern United States in winter, and to a somewhat less degree in Europe. Temperature changes with passing storms are especially marked in winter, when latitudinal temperature gradients are steepest and importations by winds consequently most severe. In summer, with the poleward migration of the storm belt, cyclones are fewer and weaker; temperature gradients are milder; and sun control, with its daily periodicity, is more influential. In that season, then, weather changes are more regular and diurnal and less marked.

It is incorrect to conceive of cyclonic control as identical in different parts of the earth. Even within the United States storms act differently over the Pacific Coast or the western plateaus from the way they do in eastern United States. Northwest winds on the rear of a cyclone obviously cannot import very low temperatures if they come from over the ocean, as they do in northwestern Europe or the Pacific Coast of the United States. Storms differ in character with

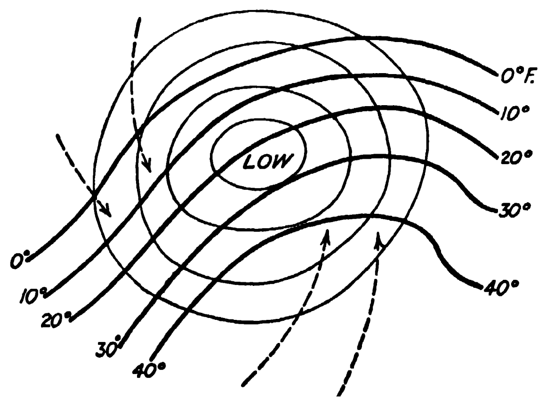
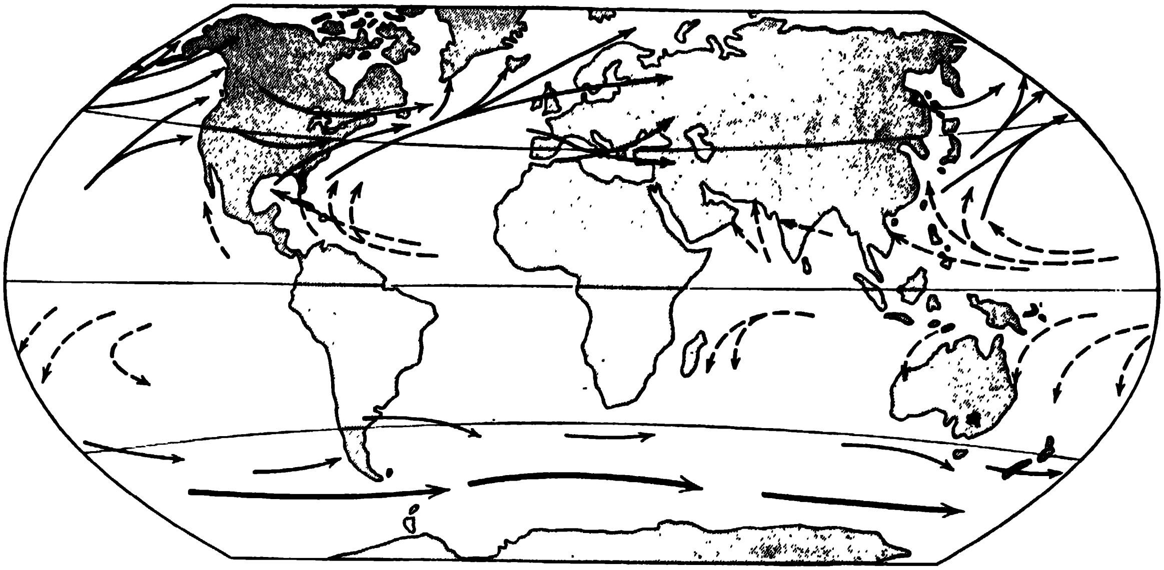


Fig. 71. Characteristic arrangement of isotherms in a winter cyclone over central and eastern United States.



→ Principal tracks of extra-tropical cyclones

– – – –→ Principal tracks of tropical cyclones

Fig. 75. The cyclone tracks here shown are much simplified. (*From Petterssen.*)

appears to be associated with moving fronts bounding unlike air masses. If this is true then the middle latitudes, which are the meeting place of air masses from the tropics and from the polar regions, should be the part of the earth where cyclones are most numerous and most vigorous. That such is the case is demonstrated by the extremely variable weather of the middle latitudes.

All parts of the middle latitudes, and likewise the adjacent margins of the low and high latitudes, are affected by moving cyclones and anticyclones. In the low latitudes as well, there is increasing evidence for believing that cyclones play a relatively important role in weather. All parts, however, are not affected to the same degree, for, although there is no rigid system of clearly defined *storm tracks*, there are, nevertheless, certain broad belts over which storms travel more frequently than elsewhere. These are the regions of most numerous and most active fronts. Of course the effects of a storm are felt far beyond the path of its center. Figure 75 shows in a generalized way the principal cyclonic tracks of the world.

In the Southern Hemisphere, as a result of a very stable and intense anticyclone over the Antarctic Continent providing abundant supplies of cold polar air throughout the year, there is great year-round vigor of cyclonic storms, in summer as well as in winter. One zone of convergence, and therefore of cyclo-genesis, is along the antarctic front separating *cP* air originating over the Antarctic Ice Cap, from *mP* air which develops over the surrounding polar seas (Figs. 59 and 60). The second zone of convergence is located somewhat farther north where *mP* air conflicts with *mT* air in the vicinity of latitude 40°. This is the polar front. The cyclones which develop along the Southern Hemisphere polar fronts greatly affect the weather of South America south of 30°S. and the southern extremities of Africa and Australia. The Cape Horn region of South America, extending as it does to nearly latitude 55°S., is a stormy area at all times of the year. Winter cyclones are likewise relatively numerous over the Pampa of Argentina.

168. *Northern Hemisphere Tracks.* The less vigorous (except in winter), and likewise less persistent, continental anticyclones forming over the arctic and subarctic regions provide the principal southward gushes of cold polar air for the formation of Northern Hemisphere storms.

The arctic and subarctic anticyclones are relatively weak in summer, which accounts for the poleward migration of the storm tracks as well as for the general weakening of cyclonic control over the whole Northern Hemisphere in that season. In winter, on the other hand, when the arctic and subarctic high-pressure centers are much better developed, and therefore are able to provide the necessary southward surges of cold air, storms are both numerous and vigorous. The principal concentration of cyclones is in the North Pacific (Aleutian low), northern United States and southern Canada, the North Atlantic (Iceland low), and northwestern Europe.

The concentration of cyclonic tracks is relatively coincident with the main frontal zones (Figs. 59 and 60). Since the frontal zones are not stationary but migrate north and south with the seasons and also irregularly from day to day, the tracks of cyclones must also vary in position. In the North Atlantic many winter cyclones originate in the area of steep temperature gradients off the Atlantic coast of the United States. A large percentage of these storms travel toward the Icelandic low and then either follow the arctic front into the polar seas north of Scandinavia, or enter northern Europe by way of the Baltic Sea. An important secondary European track follows the winter front which coincides with the Mediterranean Sea. The pattern of cyclonic tracks in the North Pacific resembles that just described for the Atlantic with the principal region of origin coinciding with the frontal zone of steep temperature gradients off the east coast of Asia. The storms take a northeastward path through the Aleutian low and on toward the west coast of North America. Some of these storms cross the continent. The open nature of the continent east of the Rockies makes central and eastern North America a remarkedly good zone of conflict between tropical and polar air masses of greatly contrasting temperatures. Numerous cyclones thus develop along secondary fronts over the continent, causing central and eastern North America to be a particularly stormy area in winter.

In the cold season there appears to be a tendency for storm tracks to dip southward over the continents, thereby avoiding the continental highs, and to swing poleward over the oceans, passing through the centers of the permanent lows and following the belt of marked temperature contrasts. Cyclones have been known to travel entirely around the earth. One such storm, with its center on the American Pacific Coast on Feb. 23, 1925, was traced completely around the globe, arriving again on the Pacific Coast on Mar. 19.

In the United States there appears to be a general bunching of cyclonic storm tracks in the northwestern and northeastern parts of the country, with a spreading and southward looping of them over the interior (Fig. 76). The northeastern and northwestern sections of the country in winter obviously must have much changeable weather with abundant cloud and precipitation. Most storms follow the northern rather than the southern routes across the country, a fact of utmost importance in understanding American weather.

169. The Weather Map and Weather Forecasting.[1] People are by instinct weather forecasters, for there is an inherent craving for information about approaching atmospheric phenomena. The numerous current weather proverbs indicate this craving. One may learn roughly to foretell weather conditions, even without instruments or maps, by merely being observant of such local indicators as direction of wind, kinds of clouds, and rising or falling temperatures. However, a much more accurate job of forecasting can be done if one has access to certain instruments, particularly a barometer. The U.S. Weather Bureau's daily forecasts are based upon data from about 300 first-order and about 450 second-order stations. By radio, teletype, telephone, and telegraph weather reports from these several hundred stations are relayed to forecast centers and to the central office at Washington, D.C., for analysis and charting.

[1] See "Climate and Man." Yearbook of Agriculture, 1941. Pp. 128, 153, 579-598. U.S. Government Printing Office, Washington, D.C. Pamphlets on the U.S. Weather Bureau and its forecasting services may be obtained from the Superintendent of Documents, Washington, D.C.

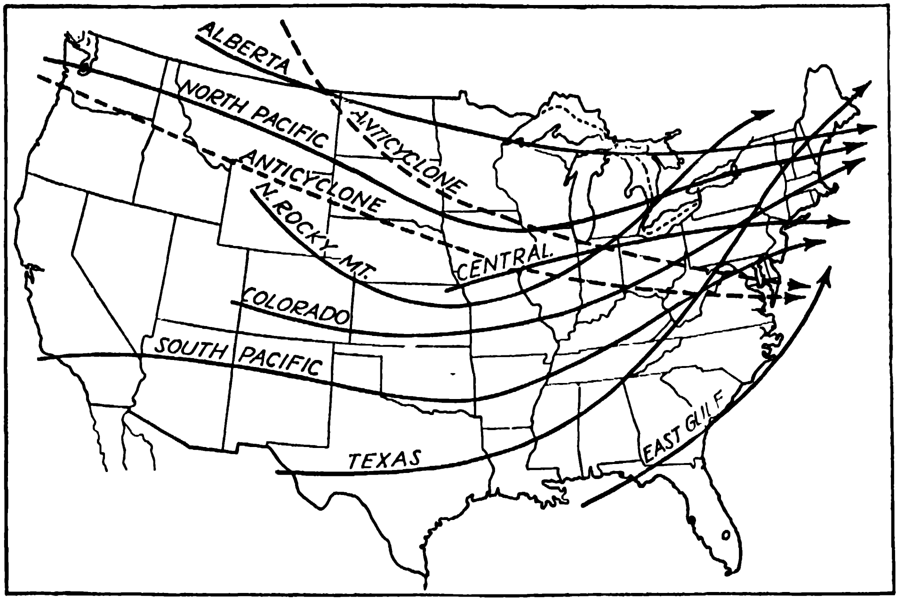


Fig. 76. Solid lines show principal tracks of cyclones; broken lines are the principal tracks of anticyclones. Note how the cyclone tracks converge on the northeastern part of the United States. Anticyclones moving south from northern Canada (*cP* air) bring severe cold in winter; those from the Pacific northwest (*mP* air) bring only moderate cold.

At more than 100 weather stations upper air weather observations are taken by means of pilot balloons, and at over 30 stations upper air observations of temperature, pressure, and humidity are made by means of radiosondes. The latter are miniature radio transmitters which are carried up to heights of 50,000 to 75,000 ft. by balloons. Supplementing the weather reports from stations within the United States are others received from Canada, Mexico, Central America, Puerto Rico, and Panama and from ships at sea.

In the United States complete weather observations are made four times a day at 6-hr. intervals, beginning at 1:30 A. M. eastern standard time. At most airway stations observations are made hourly. The whole atmosphere is the forecaster's laboratory, but this is too large for him to comprehend without first reproducing it on a miniature scale on a map. This is the weather map, sometimes called a synoptic chart (Figs. 66 and 68). On this map are represented graphically the data obtained from simultaneous observations at the several hundred stations. At airway stations weather maps are made at 6-hr. intervals for 8 hr. following. The published U.S. Weather Maps are prepared from the 1:30 A.M. and the 7:30 A.M. observations. On the maps prepared at the weather stations, there are represented in addition to the conditions of temperature, pressure, wind, cloudiness, and precipitation, the distribution of air masses and the fronts that bound them.

The techniques of weather forecasting do not properly belong in a book of this sort, and only a few of the most general types of comment are offered. Forecasting involves trying to picture the changes in storms and fronts during the subsequent forecast period. The concept of middle-latitude weather changes as resulting chiefly from the interaction of contrasting air masses has resulted in recent years in the application of new techniques in forecasting methods. No longer is weather viewed in simply a two-dimensional aspect as represented by surface isobars on the ordinary weather map. There is an increasing attempt to understand atmospheric conditions vertically as well as horizontally. To do this there are constructed maps of the various weather elements at different levels aloft as well as at the surface. Such maps are made possible by the data obtained from the

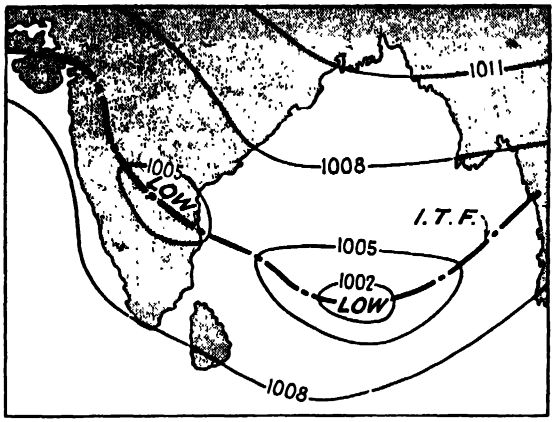


Fig. 77. Weak tropical lows over India and the Bay of Bengal.

ascent of radiosondes. Accurate weather forecasts for more than a few days, or at most a week in advance, are not yet practicable except in a very limited number of instances.

TROPICAL CYCLONES

Weak Tropical Lows[1]

170. There are tropical cyclones of all degrees of intensity within those parts of the low latitudes where heat and humidity are abundant. It is those violent storms with wind velocities in excess of 75 miles per hour, called hurricanes or typhoons, which have received much the greatest amount of attention from students of weather. But although the hurricane type of cyclone is, to be sure, the most spectacular and destructive storm of the tropics, it is by no means the most important climatically. Their relative infrequency as compared with the more numerous and widespread weaker cyclones reduces their climatic significance. The less vigorous tropical cyclones have received little attention, probably because they are less severe and do little damage.

These shallow barometric depressions, here designated as *weak tropical lows* to distinguish them from the hurricane variety, may not be conspicuous on the weather map, often showing only as bulges in the general isobaric setup or perhaps with a few closed isobars (Fig. 77). A smaller number develop greater intensities. Their wind systems commonly are not well developed, a definite cyclonic arrangement often being absent. Feeble winds and much calm seem to prevail. Westerly drift of these storms is evident in some parts of the tropics, but definite tracks are not conspicuous, stagnation and tangled paths being more common. Temperature effects are negligible. It is in the rainfall element that they become particularly conspicuous and significant, for frequently they are productive of beneficial rainfall, not always supplied in sufficient amount by the simple convectional showers typical of these regions. When these same weak disturbances remain nearly stationary over a limited area for several days, the rainfall may even become excessive, resulting in damaging floods. Without doubt too large a percentage of tropical rainfall has been ascribed to local convection resulting from surface heating, and too little to the effects of these weak tropical lows which certainly are more numerous and widespread as well as more beneficial, than are the better known hurricanes.

These weak cyclones of the humid tropics appear to originate as wavelike disturbances along tropical fronts. Most of them probably do not grow much beyond this stage and so appear as only shallow barometric depressions accompanied by widespread cloud and rain. There is good evidence that hurricanes have their beginnings as weak tropical lows.

Weak cyclones of probable frontal origin, resembling those of the tropics, are not unknown in humid subtropical parts of middle latitudes as well, although there they are confined to the warm season. They are best known perhaps in the Yangtze Valley of China and over the southern half of Japan. In the latter country they give rise to an unpleasant and depressing rainy season extending from about mid-June to mid-July, during which the sky is overcast much of the time and more or less rain falls nearly every day. The air is so damp that walls and pavements remain wet and furniture and clothes become moldy. These *Bai-u* rains (mean-

[1] Stephen S. Visher. Frequency of Tropical Cyclones, Especially Those of Minor Importance. *Monthly Weather Rev.*, Vol. 58, pp. 62–64, February, 1930.

a. Local, intra-air-mass, heat thunderstorms occur sporadically owing to local convection and are associated with weak barometric gradients and hot, relatively stagnant, humid air (Fig. 79). They are typically storms of the tropics and subtropics, although they are reasonably numerous in warm parts of the middle latitudes in summer. The heat, humidity, and slight air movement characteristic of the doldrums furnish ideal conditions for their development and growth. These local storms, many of them small and ephemeral, although not always so, are usually confined to early afternoon or evening on hot summer days with abundant humidity. An unstable condition results from overheating of the quiet, humid, surface air, so that convection and towering cumulus clouds are often the result. If the latter grow to cumulo-nimbus size, they may give rise to a thundershower. Such scattered local storms may travel in almost any direction, although usually in the middle latitudes they move toward the east. Literally hundreds of these ephemeral thundershowers may dot southeastern United States on a hot summer day. It is impossible to forecast the exact time or place of their occurrence. They are of great economic significance, for they produce a considerable part of the summer precipitation in the interiors of middle-latitude continents and probably a still larger part of that which falls in tropical latitudes.

Willis I. Milham gives the following excellent description of a local thunderstorm:

> It has been a hot, sultry, oppressive day in summer. The air has been very quiet, perhaps alarmingly quiet, interrupted now and then by a gentle breeze from the south. The pressure has been gradually growing less. The sky is hazy; cirrus clouds are visible; here and there they thicken to cirro-stratus or cirro-cumulus. The temperature has risen very high, and the absolute humidity is very large, but owing to the high temperature the relative humidity has decreased somewhat. The combination of high moisture and temperature and but little wind has made the day intensely sultry and oppressive. In the early hours of the afternoon, amid the horizon haze and cirro-stratus clouds in the west, the big cumulus clouds, the thunderheads, appear. Soon distant thunder is heard, the lightning flashes are visible, and the dark rain cloud beneath comes into view. As the thundershower approaches, the wind dies down or becomes a gentle breeze blowing directly toward the storm. The temperature perhaps drops a little as the sun is obscured by the clouds, but the sultriness and oppressiveness remain as before. The thundershower comes nearer, and the big cumulus clouds with sharp outlines rise like domes and turrets one above the other. Perhaps the loftiest summits are capped with a fleecy, cirrus-like veil which extends out beyond them. If seen from the side, the familiar anvil form of the cloud mass is noticed. Just beneath the thunderheads is the narrow, turbulent, blue-drab squall cloud. The patches of cloud are now falling, now rising, now moving hither and thither as if in the greatest commotion. Beyond the squall cloud is the dark rain cloud, half hidden from view by the curtain of rain. The thunderheads and squall clouds are now just passing overhead. The lightning flashes, the thunder rolls, big, pattering raindrops begin to fall or perhaps, instead of these, damage-causing hailstones. The gentle breeze has changed to the violent outrushing squall wind, blowing directly from the storm, and the temperature is dropping as if by magic. Soon the rain descends in torrents, shutting out everything from view. After a time, the wind dies down but continues from the west or northwest, the rain decreasing in intensity; the lightning flashes follow each other at longer intervals. An hour or two has passed; it is growing lighter in the west; the wind has died down; the rain has almost stopped. Soon the rain ceases entirely; the clouds break through and become fracto-stratus or cirriform; the temperature rises somewhat, but it is still cool and pleasant; the wind has become very light and has shifted back to the southwest or south. Now the domes and turrets of the retreating shower are visible in the east; perhaps a rainbow spans the sky; the roll of the thunder becomes more distant; the storm has passed, and all nature is refreshed.[1]

b. Cold-front Thunderstorms. Some thunderstorms are genetically associated with the fronts of moving cyclones and are the result of the upthrust of air that occurs in these areas of

other than the one here discussed. In all cases they are probably due to the conflict of air currents of different temperatures and densities, resulting in atmospheric overturning.

[1] W. I. Milham. "Meteorology." Pp. 321–322. The Macmillan Company, New York, 1934.

local convergence. Although thunderstorms may form along warm fronts and occluded fronts, they are most numerous and most severe along cold fronts, especially those of well-developed V-shaped summer cyclones (Fig. 80*A*). The cold front marks the abrupt meeting place of warm, humid, southerly currents on the front of the cyclone, with the cooler, heavier air of the northwest winds on the rear. Thunderstorms may form a nearly continuous series of active centers hundreds of miles long, the individual storms strung out along the cold front (sometimes called the squall line) like beads on a string. Usually, however, they are some distance apart. When the cool westerly winds strike the side of the warm southerly currents along the cold front, they either underrun it like a blunt wedge or, owing to surface friction, overrun a portion of the warm air and entrap it (Fig. 64*e*). In either case vigorous overturning and upthrust take place with resulting turbulence and associated development of thunderstorms. Occasionally tornadoes, those most violent of all windstorms, likewise develop at or near the cold front of V-shaped cyclones. Since the cold-front variety of thunderstorm is associated with a frontal zone, it must of necessity travel with the latter, and its approach and passage, therefore, can be forecast with a considerable degree of accuracy. In general, a cold-front storm can be distinguished from the local heat variety by the following criteria: (*a*) The former is commonly more severe although by no means always so. (*b*) It is not confined to any particular time of day, for its origin does not depend upon local surface heating. It may arrive, therefore, at any time of day or night. Local convectional storms, on the other hand, more commonly are concentrated in the warmer hours of the day. (*c*) The cold-front thunderstorm is usually followed by a shift of wind from southwest, south, or southeast to northwest (from a tropical to a polar air mass) and by a consequent drop in temperature (Fig. 80*B*). The local heat thunderstorm gives only a very temporary relief from the heat during the period of cloud cover and rain and is likely to be followed by the same kind of hot, humid weather that preceded it.

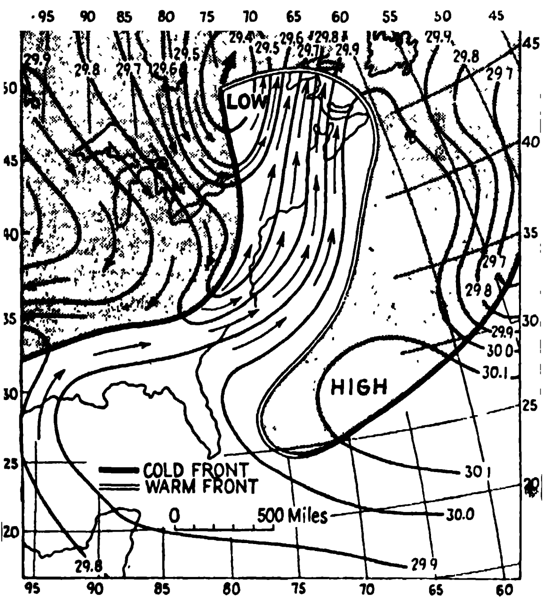


Fig. 80*A*. A V-shaped summer cyclone with a well-developed cold front and severe thunderstorms. Regions covered by air of polar origin are shaded; those covered by air of tropical origin are left unshaded.

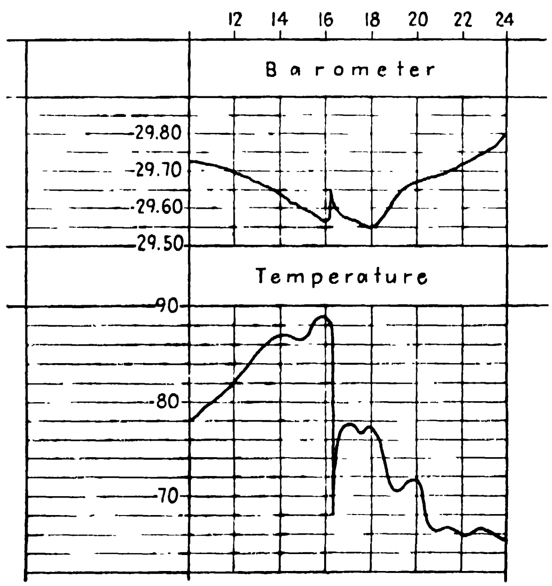


Fig. 80*B*. Record of pressure and temperature at the Naval Air Station, Anacostia, D.C., during the approach and passage of the squall-line storm shown in Fig. 66. Hours indicated at top.

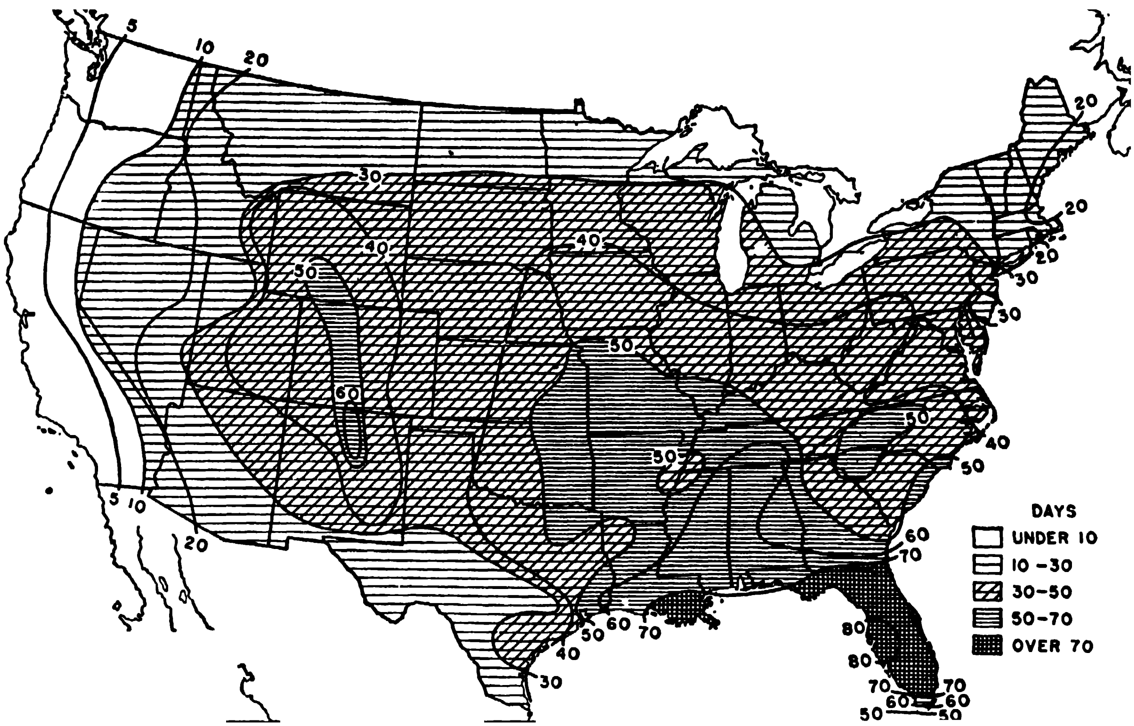


Fig. 81. Distribution of thunderstorms. Figures indicate average annual number of days with thunderstorms.

180. Distribution of Thunderstorms. Since in the doldrum belt, with its constantly high temperatures, stagnant air, and high humidity, are to be found the most ideal conditions for thunderstorm formation, it is not surprising that equatorial regions should have the maximum number of days with such phenomena. There is a general decrease in their frequency of occurrence from equator to poles but with many variations. In the region of the doldrums thunder is heard on 75 to 150 days a year, and there are a few places recording more than 200 such days. The low-latitude deserts, however, also in the tropics and likewise hot, have fewer than 5 days with thunder, relative humidity being too low for thunderstorm formation. In middle latitudes there is a marked excess of thunderstorms over land as compared with sea. Thunder is rarely heard in the polar areas. Southeastern United States is the most thundery area outside the tropics, there being 70 to 90 days a year with such storms over the central and eastern littoral of the Gulf of Mexico. A portion of New Mexico has over 60 (Fig. 81). The number decreases to the north and west, the central tier of states having 50 ±, the northern tier 25 to 40, and the Pacific Coast fewer than 5.

181. Tornadoes, the most violent and destructive of all storms, fortunately are of rare occurrence and very restricted in area, their diameters usually being only 300 to 1,500 ft. They are closely associated with thunderstorms of the cold-front variety and characteristically occur slightly to the east of the cold front in well-developed V-shaped cyclones. Spring and early summer witness their maximum development. The approach of a tornado is usually heralded by dark and greenish masses of cumulonimbus clouds in wild turmoil, from which descends the funnel-shaped tornado cloud. Upper air currents carry the storm in a general northeasterly direction, the rate of movement averaging 25 to 40 miles an hour. The destruc-

tive effects of tornadoes are of dual origin: (*a*) the high horizontal and vertical wind velocities, the former estimated at 100 to 500 miles per hour and the latter at 100 to 200; and (*b*) the explosive effect upon buildings of the low pressure at the center of the storm. Tornadoes are sometimes referred to as "twisters" because of the inward and upward spiraling masses of air which comprise them. They appear to be typically American phenomena, for they are relatively rare in other parts of the world. In the United States they are most frequent over the central and southern states east of the Rockies.

SECTION B: *Climatic Types and Their Distribution*

182. In the four preceding chapters the individual elements out of which climates are composed have been analyzed and their distributions over the earth's surface described. Variations in the amount, intensity, and seasonal distribution of these elements, as determined by the climatic controls, resulting in changeful combinations of the elements, are the reason for the existence of the variety of climates, the description of which is to follow.

183. Classification by Temperature Zones. Perhaps the broadest and most general classification of climates is the one devised by the ancient Greeks who divided each hemisphere into three broad belts, or zones. Thus in the low latitudes is the *winterless* tropical region where temperatures are high throughout the year. Similarly in the high latitudes, in the vicinity of the poles, are the *summerless* polar regions, where there is a general prevalence of low temperatures. Between these two extremes, which are the tropical and the polar parts of the earth, are broad intervening belts where seasonal contrasts in temperature are marked, one season usually being warm or hot, and the other cool or cold. These are the *intermediate*, or *middle*, *latitudes*, sometimes designated as the "temperate zones," although obviously that name is not well chosen. The boundaries of these insolation or temperature zones as suggested by the ancients are the 23.5° and the 66.5° parallels in each hemisphere. For these unsatisfactory astronomical boundaries modern geographers have substituted certain critical isotherms, such as the 64° *coolest* month isotherm for the poleward limits of the tropics and the 50° *warmest* month isotherm for the poleward limits of the intermediate zones.

184. Climatic Regions and Climatic Types. This threefold classification of the earth's climates into tropical, middle-latitude, and polar types plainly does not take into consideration that other great climatic element, precipitation, since within both the low and the middle latitudes there are very wet as well as very dry climates. It is obvious that the geographer requires not only a more detailed and refined classification, but likewise one in which both temperature and precipitation are considered when making the climatic subdivisions. Such a subdivision of the land areas of the earth into climatic types and climatic regions is presented on Plate III.

Any portion of the earth's surface over which the climatic elements, and therefore the broad climatic characteristics, are similar (not necessarily identical) is called a climatic region. But it will be noted that not all the subdivisions on Plate III differ from one another climatically, for areas with similar climates are found in widely separated parts of the earth, although often in corresponding latitudinal and continental locations. This frequent duplication of climates in roughly corresponding positions on the continents suggests that there is order and system to the origin and distribution of the climatic elements. It likewise makes possible the classification of the numerous *climatic regions* into a relatively few principal *climatic types*. The degree of order and system to be observed in the latitudinal and continental arrangement of climatic types is associated with the distribution of solar energy and the planetary winds, with their associated zones of horizontal convergence and divergence, these controls providing a rough framework for the climatic

pattern of the earth. That there are numerous modifications of, or deviations from, any rigid scheme suggests the operation of other controls, some of which are not entirely understood. For the latter reason not all the facts of climatic distribution are at present explainable.

185. General Scheme of Climatic Classification. In its broader aspects the general scheme or outline of climatic subdivision here employed follows the Köppen system.[1] In the low latitudes near the equator is a winterless region *A* with adequate rainfall. This is the humid tropics. Poleward from this belt, and extending beyond the tropics far into the intermediate latitudes, are the dry climates *B*, sometimes designated as the "death zones." The humid middle latitudes *C* and *D*, with their seasonal contrasts in temperature, are divided into two climatic groups, one in which the winters are short and mild (*C*), and the other in which they are severe and long (*D*). Finally in the higher latitudes are the summerless polar climates *E*. In more detail the outline of principal climatic types and their subdivisions appears on page 130.

In order to facilitate shifting back and forth between the Köppen system of classification and the modified and simplified form of that scheme here employed, the corresponding Köppen symbols appear in parenthesis after each type of climate. Since the two classifications are *similar*, but not *identical*, the latter symbols indicate only somewhat comparable climates and should not be understood to imply complete agreement.[2]

186. Distribution of Climates on a Hypothetical Continent. In studying the text materials on types of climate to follow, constant reference should be made to Plate III, showing distribution of the types over the land areas of the earth. In conjunction with the analysis of actual distribution as exhibited on Plate III, careful attention likewise should be paid to Fig. 82. It is designed to show the typical positions and arrangements of the climatic types as they would appear on an idealized continent of low and uniform elevation, the shape of which roughly corresponds to that of the actual land masses. In other words, on this hypothetical continent one is able to see the climatic types as they probably would be, with the modifications and complications resulting from varying shapes, sizes, positions, and elevations of the land masses eliminated. The strong resemblances between Fig. 82 and Plate III are obvious.

[1] See W. Köppen, "Grundriss der Klimakunde." Walter De Gruyter & Company, Berlin, 1931. The particular value of Köppen's classification lies in the fact that it is a quantitative system, which uses numerical values for defining the boundaries of the climatic groups and types. Where exact definitions are given to the lines limiting the climatic types, the boundaries are subject to checking and revision as new data are available. The Köppen system has been so widely adopted that it is something of a world standard. Another valuable world classification of climates, likewise employing numerical values of temperature and rainfall for defining the boundaries of climatic types, is by C. Warren Thornthwaite (see references, p. 133). Both the Köppen and the Thornthwaite classifications, representing quantitative systems of comparative climatology, are particularly useful to professional geographers or to college students who are training to enter that field. It is the authors' belief, however, that in an introductory book in geography for college freshmen and sophomores, scarcely any of whom will become geographers, major emphasis should be placed upon the descriptive elements of a climate rather than upon the values employed to establish boundaries, especially since these values are still somewhat tentative. For this reason no attempt has been made to impress the student with the necessity of memorizing the specific Köppen formulas, the more important ones of which are given below for those who desire to use them. Definitions of other Köppen symbols are given in footnotes at the points where they may be useful.

A = temperature of coolest month over 64.4° (18°C.)
B = evaporation exceeds precipitation
C = coldest month between 64.4° (18°C.) and 26.6° (−3°C.)
D = temperature of coldest month under 26.6° (−3°C.); warmest month over 50° (10°C.)
E = temperature of warmest month under 50° (10°C.)

[2] One of Köppen's principal climatic types *Cw* is here omitted. It is felt that this climate is not sufficiently distinctive to warrant setting it apart, for the purpose of this classification, as a separate type.

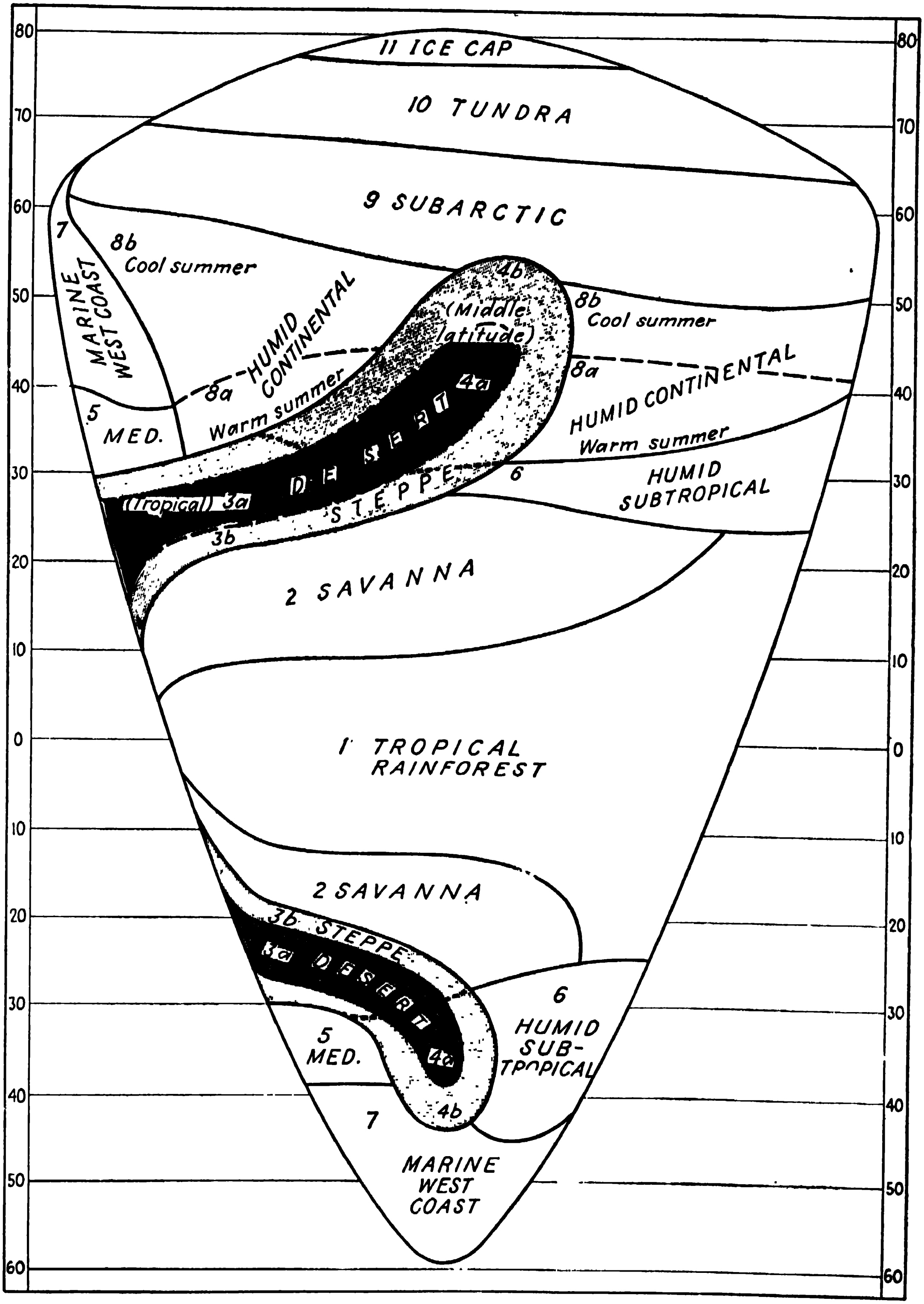


Fig. 82. Arrangement of the principal climatic types on a hypothetical continent of low and uniform elevation.

*Types of Climate**

Groups	*Types*
	I. *Low Latitudes (The Tropics)*
A. Tropical rainy climates	1. Tropical rainforest: *Af*, constantly wet; *Am*, monsoon variety
	2. Tropical savanna (*Aw*, wet and dry)
B. Dry climates	3. Low-latitude dry climates
	a. Low-latitude desert (*BWh*, arid)
	b. Low-latitude steppe (*BSh*, semiarid)
	II. *Middle Latitudes (Intermediate Zones)*
	4. Middle-latitude dry climates
	a. Middle-latitude desert (*BWk*, arid)
	b. Middle-latitude steppe (*BSk*, semiarid)
C. Humid mesothermal climates	Mediterranean or dry-summer subtropical (*Cs*)
	6. Humid subtropical (*Ca*)
	7. Marine west coast (*Cb*)
D. Humid microthermal climates	8. Humid continental climates:
	a. Humid continental, warm summer (*Da*)
	b. Humid continental, cool summer (*Db*)
	9. Subarctic (*Dc*, *Dd*)
	III. *High Latitudes (Polar Caps) or High Altitudes*
E. Polar climates	10. Tundra (*ET*)
	11. Ice cap (*EF*)
H. Undifferentiated highlands	

* Temperature and precipitation data for representative stations are included for each type of climate. It is expected that data for selected stations will be plotted on the coordinate-paper blocks provided in Plate II. Supplementary climatic data can be found in Appendix A.

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CHAPTER 7: *The Tropical Rainy Climates (A)*

187. Location and Boundaries. The humid tropics comprise a somewhat interrupted and irregular "belt" 20 to 40° wide, around the earth and straddling the equator (Fig. 82, Plate III). This region is distinguished from all other humid regions of the earth by reason of the fact that it is constantly warm; in other words, *it lacks a winter.* In the humid tropics summer heat is a less important factor than a season of coolness, during which there is some relief from high temperatures. As a consequence, the poleward boundary of the tropical rainy climates, except where they come in contact with the dry climates, is, according to Köppen, approximately the isotherm of 64° for the *coolest month.* Stated in a different way, within this climatic group there is no month with an average temperature of less than 64°. This temperature was selected because it was found to coincide reasonably well with the poleward limit of certain plants which grow only in the warmest regions and cannot tolerate marked seasonal changes in temperature. The chief interruptions in the belt of humid tropical climates over the continents are caused by mountains and plateaus, these elevated lands, even though near the equator, having temperatures too low to permit them to be classed as typically tropical.

Normally the tropical rainy climates extend farthest poleward along the eastern or windward sides of the continents (Fig. 82). Here tropical maritime air masses (trades) come onshore from off warm waters and provide atmospheric conditions conducive to thunderstorm and cyclonic precipitation. East coast rainfall is especially heavy where the tropical air masses are forced to ascend highland barriers. Hurricanes are likewise prevalent along certain of the tropical east coasts. On these windward sides of the land masses, therefore, the humid tropical climates extend poleward until they meet the humid subtropical climates of the middle latitudes. In the interior, and toward the western sides of the continents, however, the humid tropics are bounded by the dry *B* climates. As the trades sweep farther inland, their aridity increases, so that in the continental interiors dry climates are brought somewhat closer to the equator. Where cool equatorward-moving ocean currents parallel the west coasts in low latitudes, they may carry the dry climates to within a few degrees of the equator, notably constricting the breadth of the humid tropical belt. Likewise these western sides of tropical continents are fairly coincident with the eastern ends of subtropical high-pressure cells, where the subsiding air is stable and opposed to precipitation.

188. Precipitation. Rainfall is relatively abundant, rarely lower than 30 in., and usually it is well over that amount (Plate I). Much of the precipitation is convectional in origin, the heavy showers often being accompanied by severe thunder and lightning. Cyclonic rains associated with weak tropical lows are likewise important. Unlike the uniform temperature conditions, rainfall is more variable in amount and in both seasonal and areal distribution. The two principal climatic types within the humid tropics are distinguished from each other on the basis of their seasonal distribution of precipitation, one type, tropical rainforest, having ample rainfall throughout the year, while in the other, savanna, there is a distinctly wet and a distinctly dry season.

1. Tropical Rainforest Climate (Af and Am)[1]

189. Location. (*a*) Uniformly high temperatures and (*b*) heavy precipitation distributed throughout the year, so that there is no marked dry season, are the two most distinguishing characteristics of the Af, or tropical rainforest, climate. When typically located it is found astride the equator and extending out 5 or 10° on either side. This latitudinal spread may be increased to 15 or even 25° along the windward margins of the continents.

TEMPERATURE

190. Annual and Seasonal Temperature. Lying as it commonly does athwart the equator and consequently in the belt of maximum insolation, it is to be expected that temperatures will be uniformly high, the yearly averages usually lying between 77 and 80°+ (see data, pages 140 and 141). Since the sun's noon rays are never far from a vertical position, and days and nights vary little in length from one part of the year to another, the annual insolation curve remains relatively constant, so that not only are the annual temperatures high, but there is likewise little seasonal variation (Fig. 83). What slight seasonal temperature variations exist do not necessarily follow those of insolation (Fig. 17), so that two maxima and two minima on the annual temperature curve are not common. Seasonal variations in cloudiness and precipitation often are more important than insolation in determining the small seasonal variations in temperature. The annual temperature range, or difference between the warmest and coolest months, is usually less than 5°. Thus Belém and Iquitos in the Amazon Valley have annual ranges of 3° and 4.3°, respectively; Coquilhatville in central Africa, 2+°; and Singapore in southern Malaya, 3.2°. Over the oceans in these low latitudes ranges are even less, Jaluit in the Marshall Islands in mid-Pacific recording only 0.8° difference between the extreme months. It becomes evident from the very small temperature ranges that it is not the excessively high monthly averages but rather the *uniformity* and *monotony* of this constant succession of hot months, with no relief, that characterizes the tropical rainforest climate. Thus the average July temperatures of many American cities, such as Charleston, with 81.6°; Galveston, 83.3°; and Montgomery, 81.6°, may equal, or even exceed by a few degrees, those of the hottest months at stations near the equator. The hottest month at Belém (Amazon Basin) is only 79.7°, and at Akassa (Niger Delta), 79.9°.

191. Daily Temperatures. The daily or diurnal range of temperature (difference between the warmest and coolest hours of the day) is usually 10 to 25°, or several times greater than the annual range. For example, at Bolobo in the Belgian Congo, the average daily range is 16°, while the annual range is only 2°. During the afternoons the thermometer ordinarily

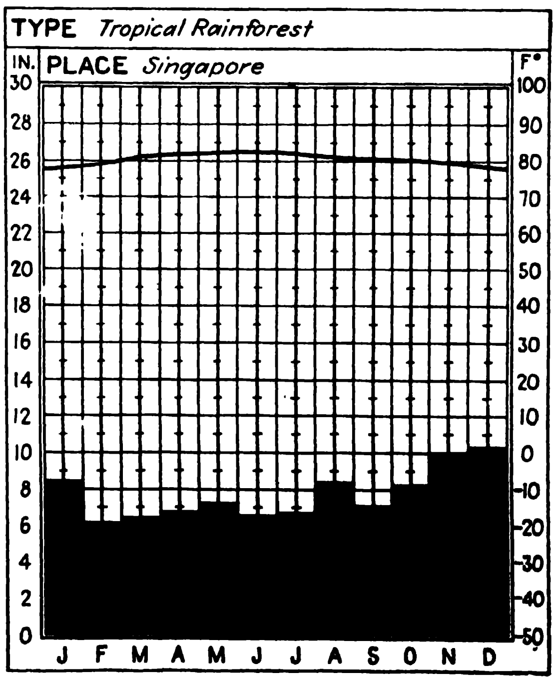

Fig. 83. Average monthly temperatures and precipitation for a representative station in the tropical rainforest climate.

[1] In the Köppen symbols f = moist (*feucht*) throughout the year, no month with less than 2.4 in. of rain; m = monsoon variety, with heavy annual rainfall but a short dry season.

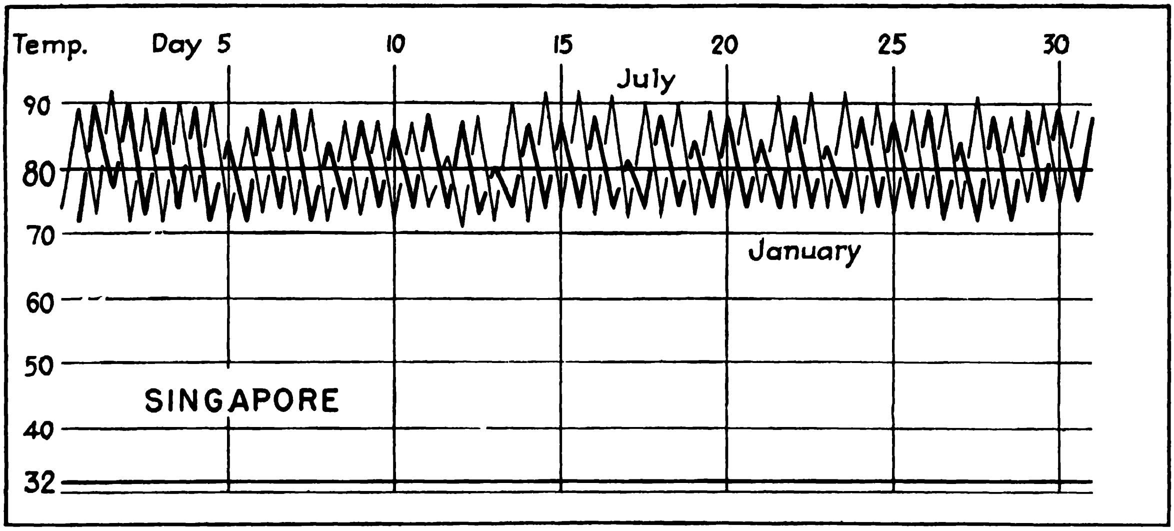

Fig. 84. Daily maximum and minimum temperatures for the extreme months at a representative tropical rainforest station.

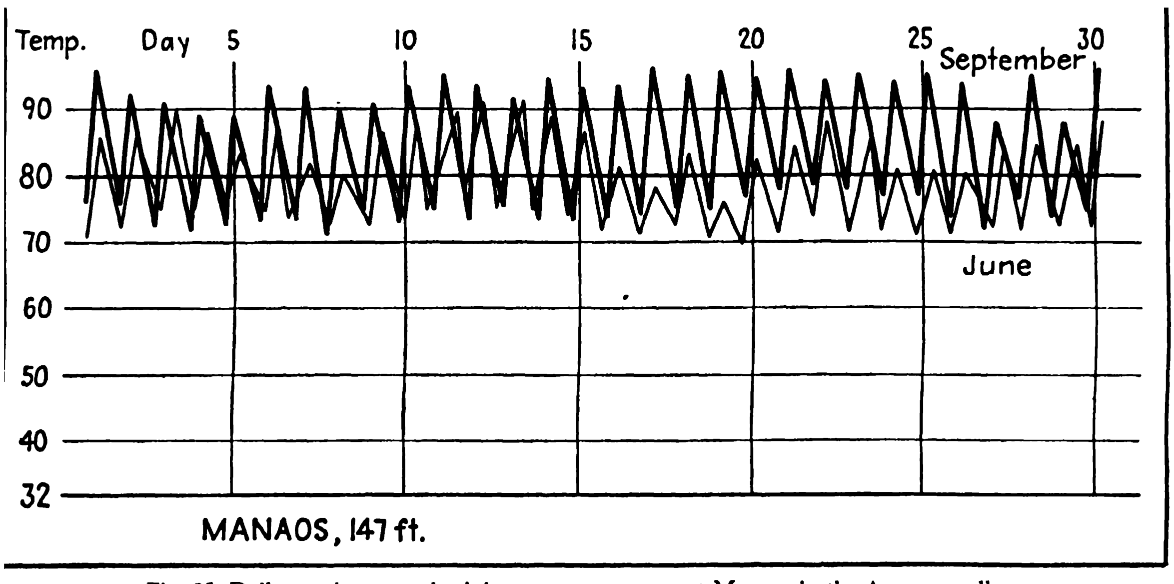

Fig. 85. Daily maximum and minimum temperatures at Manaos in the Amazon valley.

rises to temperatures varying from 85 to 93°, and at night sinks to 70 or 75° (Figs. 84, 85, and 86). It is commonly said, therefore, that night is the winter of the tropics. Even the extremes of temperature are never very great, the average of the daily maxima at Belém being only 91.4°, and the average of the daily minima, 68°. The highest temperature ever recorded at Santarem (Amazon Basin) is 96.3°, while the lowest is only 65.3°. This absolute maximum of 96.3° may be compared with 103° for Chicago and 108° for St. Louis. Although the day temperatures may not be excessively high, the heat, together with slight air movement, intense light, and high relative and absolute humidity, produces an atmospheric condition with low cooling power. It is oppressive and sultry so that one's vitality and energy are sapped.

Sensible temperatures are, therefore, excessively high, although the thermometer readings may not indicate abnormal heat.

Even the nights give little relief from the oppressive heat. Rapid nocturnal cooling is not to be expected in regions of such excessive humidity and abundant cloudiness. It is usually sufficient, however, to cause surface condensation in the near-saturated air, so that radiation fogs and heavy dew are common. The periods of less rainfall and clearest skies have the lowest night temperatures, the thermometer on rare occasions falling below 60°.

192. Daily March of Temperature. Figures 84, 85, and 86 show the daily march of temperature for the extreme months at representative stations within tropical rainforest climate. The graphs illustrate a temperature regime in which sun is almost completely in control. There is a marked diurnal regularity and periodicity about the changes, temperatures rising to about the same height each day and falling to about the same level each night, so that one 24-hr. period almost duplicates every other. Irregular invasions of heat and cold, of the type so common in the middle latitudes, are rare.

PRECIPITATION

193. Amount and Seasonal Distribution. Rainfall is both heavy and distributed throughout the year, there being no distinctly dry season (Fig. 83; see data, pages 140 and 141). Taken as a whole, tropical rainforest climate is coincident with the belt of the world's heaviest precipitation (Plate I). Ward estimates the average rainfall of the doldrum belt to be in the neighborhood of 100 in., with less over the continents and more over the oceans. Because of the abundant precipitation, surface ocean waters in the doldrums are less salty than they are in the trades. In this region close to the equator conditions are ideal for rain formation. Of primary importance is the fact that it is a region of rising air. This results in part from the convergence and rise of trade-wind air masses along the intertropical front. In part it is due also to local convection in the warm, humid, unstable air of the doldrums. Both thunderstorms and weak cyclones are numerous, and only a small amount of lifting of the unstable air is required to produce abundant rainfall. Cloudiness, much of it cumulus in character, is relatively high in the doldrums, averaging in the neighborhood of 58 per cent. At Manaos,

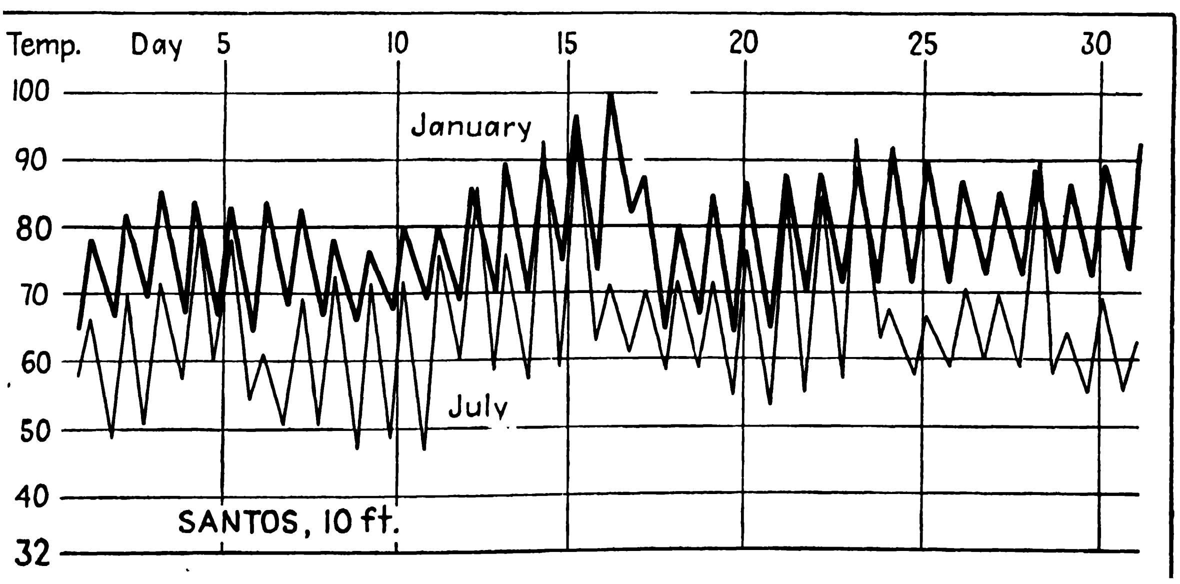

Fig. 86. Daily maximum and minimum temperatures for a tropical rainforest station on the east coast of Brazil 24° south of the equator. Note the somewhat greater nonperiodic temperature changes.

in the Amazon Valley, cloudiness varies between 6/10 and 7/10 for each month. At Belém it is 4/10 in the driest month and 8/10 in the rainiest.[1]

Although it is true that there is no genuinely dry season in the tropical rainforest climate, it should not be inferred, on the other hand, that the rainfall is evenly distributed throughout the year. By comparison with the rainiest periods there are others that are less wet, but they are far from being dry. There is no distinctive seasonal rainfall regime characteristic of the rainforest type of climate. It is not so common to find the double maxima of insolation reflected in the annual rainfall curve.

In the rainier periods precipitation falls on a large majority of the days, although there are usually a few days with none. Fewer rainy days and less rain on each day are characteristic features of the less wet seasons. At Belém in the Amazon Valley with 94 in. of rain, March (14 in.) has six and one-half times more rain than November, but even November has 10 rainy days although March has 28. Precipitation varies much more from year to year than does temperature, although these variations are seldom enough to injure crops. Even the driest years are still relatively wet.

194. Nature of the Rainfall. Much of the rainfall is convectional in origin, falling in hard showers from towering cumulo-nimbus clouds. The maximum usually occurs during the warmer hours of the day, when local heating, and therefore convectional ascent, are at a maximum. Early mornings are often relatively clear, but as the sun climbs toward the zenith and temperature increases, cumulus clouds begin to appear, growing in number and size with the heat of the day, until by afternoon ominous thunderheads are common. Several thunderstorms, accompanied by thunder and lightning, in a single afternoon are not unusual, and the rain may continue on into the evening, although there is a tendency for the skies to become clearer as the heat wanes. The cloud cover and downpour of rain accompanying the storm temporarily cool the air, but with its passing and the reappearance of the sun, the usual oppressive conditions are reestablished. Within the doldrum belt thunderstorms reach their maximum development for any latitude of the earth, there being on the average 75 to 150 days with such storms during the course of a year. These paroxysms of nature, with their fierce lightning, crashing thunder, and deluges of rainfall, are awesome spectacles. One traveler[2] writes as follows concerning the heavy convectional showers in the tropical rainforest climate:

> The force of the downpour is another factor in the oecology of the forest. In the wet season thunderstorms of great violence are frequent, and the rain descends with a suddenness and volume unknown outside the tropics. The sun is shining, the forest glitters with a million lights, birds are on the move, and insects hum and dance from leaf to leaf. All at once a shadow is drawn over the sun, and all activity of bird and beast ceases as the sound of rushing rain rapidly approaches. An avalanche of water then crashes down, blotting out surrounding objects and, as it seems, sweeping the very breath from the nostrils, bewildering and benumbing the senses. Every twig and leaf is bent and battered, and in a few seconds streams pour down the paths and the world seems changed into a thundering cataract. Then, as suddenly as it came, the storm passes, and the sun blazes out again before the roar of the storm sweeping over the treetops has died away in the distance. Even before the leaves have ceased to drip, or the land crabs, tempted forth by the teeming water, have scuttled to cover again, the life of the forest is resumed. It is almost incredible how some fragile forms escape destruction under such terrific bombardments. . . .

Weak tropical cyclones, probably of frontal origin, are likewise important rain bringers. Cyclonic rain is less intense but of longer duration and falls from more uniformly overcast gray skies. These cyclonic storms appear to be most numerous at the periods of heaviest rainfall.

195. Winds. The feeble temperature gradients beget only weak pressure gradients, so that air movement is prevailingly slight. The whole region is poorly ventilated, and this, in con-

[1] Cloudiness is here expressed in terms of the part of the total sky covered.

[2] Maude D. Haviland. "Forest Steppe and Tundra." P. 39. Cambridge University Press, London, 1926.

junction with high temperatures and excessive humidity, makes for physical discomfort. Temporary relief may be brought by the strong squall winds associated with thunderstorms. Occasionally the trades advance far enough equatorward, especially in the drier season, to bring spells of desiccating weather. This wind, known as the *harmattan* along the Guinea Coast of Africa, is usually described as a cool wind, especially at night, probably owing to its great evaporation.

Sea breezes are important climatic phenomena along coasts in the low latitudes. The importation of cooler air from the sea during the heat of the day is a great boon to residents along the littoral, causing tropical coasts to be much more livable than are the interiors.

DAILY WEATHER

196. Daily Weather Largely Sun Controlled. (Figs. 84, 85, 86.) The following description by an eyewitness, of daily weather conditions in the Amazon Valley, may serve to synthesize and vivify the previous description:[1]

> The heat increased rapidly toward two o'clock (92° and 93° Fahr.), by which time every voice of bird or mammal was hushed; only in the trees was heard at intervals the harsh whir of a cicada. The leaves, which were so moist and fresh in early morning, now became lax and drooping; the flowers shed their petals. Our neighbours, the Indian and Mulatto inhabitants of the open palm-thatched huts, as we returned home fatigued with our ramble, were either asleep in their hammocks or seated on mats in the shade, too languid even to talk. On most days in June and July a heavy shower would fall some time in the afternoon, producing a most welcome coolness. The approach of the rain-clouds was after a uniform fashion very interesting to observe. First, the cool sea-breeze, which commenced to blow about 10 o'clock, and which had increased in force with the increasing power of the sun, would flag and finally die away. The heat and electric tension of the atmosphere would then become almost insupportable. Languor and uneasiness would seize on every one; even the denizens of the forest betraying it by their motions. White clouds would appear in the east and gather into cumuli, with an increasing blackness along their lower portions. The whole eastern horizon would become almost suddenly black, and this would spread upwards, the sun at length becoming obscured. Then the rush of a mighty wind is heard through the forest, swaying the tree-tops; a vivid flash of lightning bursts forth, then a crash of thunder, and down streams the deluging rain. Such storms soon cease, leaving bluish-black motionless clouds in the sky until night. Meantime all nature is refreshed; but heaps of flower-petals and fallen leaves are seen under the trees. Toward evening life revives again, and the ringing uproar is resumed from bush and tree. The following morning the sun again rises in a cloudless sky, and so the cycle is completed; spring, summer, and autumn, as it were, in one tropical day. The days are more or less like this throughout the year in this country. . . . It is never either spring, summer, or autumn, but each day is a combination of all three. With the day and night always of equal length, the atmospheric disturbances of each day neutralising themselves before each succeeding morn; with the sun in its course proceeding midway across the sky, and the daily temperature the same within two or three degrees throughout the year—how grand in its perfect equilibrium and simplicity is the march of Nature under the equator!

[1] Henry Walter Bates. "The Naturalist on the River Amazon." Pp. 31–32. John Murray, London, 1910.

Representative Regions. The Amazon Valley in South America, the Congo Basin and parts of the Guinea Coast in Africa, and portions of the coast lands of tropical southeastern Asia, including the East Indies and the Philippines, are the three largest areas with tropical rainforest climate (Plate III). Of the two large interior regions, the Amazon and Congo Basins, the former possesses the more severe rainforest climate, having, on the whole, heavier rainfall. The trades find free entrance into the Amazon Valley through the opening between the Brazilian and the Guiana Highlands, and likewise by way of the Orinoco Valley, carrying with them enormous supplies of moisture which are precipitated as rain in the interior. Unlike the Amazon Valley, which is extremely low, the Congo Basin averages 1,000 to 1,600 ft. in elevation. Moreover, it is shut off from the sea on the east by a relatively high plateau, which prevents entrance of the trade winds. As a

Climatic Data for Representative Tropical Rainforest Stations

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Singapore, Straits Settlements (Malaya)														
Temp.	78.3	79.0	80.2	80.8	81.5	81.1	81.0	80.6	80.4	80.1	79.3	78.6	80.1	3.2
Precip.	8.5	6.1	6.5	6.9	7.2	6.7	6.8	8.5	7.1	8.2	10.0	10.4	92.9	
Belém, Amazon Valley														
Temp.	77.7	77.0	77.5	77.7	78.4	78.3	78.1	78.3	78.6	79.0	79.7	79.0	78.3	2.7
Precip.	10.3	12.6	13.3	13.2	9.3	5.7	4.9	4.3	3.2	2.5	2.3	5.1	86.7	
Nouvelle Anvers, Belgian Congo														
Temp.	79.2	80.1	79.2	78.1	79.2	78.4	76.5	76.3	77.0	77.4	77.9	78.1	78.1	3.8
Precip.	4.1	3.5	4.1	5.6	6.2	6.1	6.3	6.3	6.3	6.6	2.6	9.3	66.9	

result the rainfall is 10 to 20 in. less than in the Amazon Valley.

MODIFIED RAINFOREST TYPES

197. Smaller, and generally coastal, areas of tropical rainforest climate are to be found on the windward east coasts of (*a*) Brazil, both north and south of the equator, (*b*) Central America and the more rugged islands of the West Indies, and (*c*) the island of Madagascar. The *west* coast of South America north of the equator in Colombia is also a region of excessively heavy precipitation (Buenaventura, 281 in.) with tropical rainforest climate. Where this type of climate is found along windward coasts at some distance (15°–20°) from the equator, it exists in slightly modified form. Close to the coast the sea breeze makes the humid heat easier to bear. In addition, the closer proximity to middle latitudes permits greatly modified polar air to reach these areas occasionally in winter. The result is a greater nonperiodic variation in temperature than is true of the typical rainforest climate. Slightly lower winter minimum temperatures and somewhat greater annual ranges of temperature are also characteristic. See data for Belize and Fig. 86, illustrating conditions at Santos.

Climatic Data for Belize, British Honduras, on a Windward East Coast at about 17°20′N. Lat.

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Temp.	74.8	76.8	79.2	79.2	81.9	82.4	82.6	82.6	82.0	79.3	76.1	73.6	79.3	9
Precip.	5.1	2.6	1.6	1.5	4.1	9.1	9.6	8.5	9.4	11.0	10.2	6.3	79.0	

198. Monsoon Rainforest Climate (Am). In this subtype the total annual rainfall is commonly heavier than the average for rainforest climate. It differs from the typical rainforest climate in that precipitation is not so well distributed throughout the year, there being at least a short dry season. In annual rainfall distribution, therefore, this subtype somewhat resembles the savanna regime, although the total amount is much heavier and the dry period commonly is not so long (Fig. 87). The maximum precipitation usually occurs at the time of high sun, which is the period of the onshore monsoon. In spite of a distinct dry season, variable in length, the precipitation is so heavy that the ground remains sufficiently damp throughout the year to support a relatively dense, semideciduous forest. Temperatures usually reach a maximum during the period of clearer skies just before the season of heaviest rainfall and cloud, even though the latter is the period of highest sun (see data for Calicut on page 141). This subtype is best developed in the monsoon lands of tropical southeastern Asia and on the western Guinea Coast of Africa.

199. Resource Potentialities of the Tropical Rainforest Realm. Although approximately 10 per cent of the earth's land surface is characterized by tropical rainforest climate, by no means do these areas contain 10 per cent of the earth's population. Moreover, within the earth's tropical rainforest areas there are the widest variations in population densities. The New World tropics are far emptier than those of the Old World. The huge Amazonian region lies at one extreme with fewer than 1,500,000 people

Climatic Data for Calicut, India, a Representative Monsoon Rainforest Station

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Temp.	77.8	79.8	81.6	83.6	83.1	78.5	76.7	77.4	78.3	79.1	79.5	78.3	79.5	6.9
Precip.	0.3	0.2	0.6	3.2	9.5	35.0	29.8	15.3	8.4	10.3	4.9	1.1	118.6	

within its 1,500,000 square miles, while at the opposite pole is tiny Java with over 800 per square mile and the Ganges Delta with over 600.

Tropical rainforest is the most lavish and prolific of all climates. Here there is no dormant season for plant growth imposed either by a season of cold or a season of drought. In no other climate do plants grow so continuously and so rapidly, and since plants provide the ultimate food resource for human beings this would seem to suggest a potential maximum food production within the rainforest regions. An offsetting factor, however, is the handicap which this same climate imposes upon the health and general well-being of the people who live in it. Numerous tropical diseases, among them malaria, sleeping sickness, yellow fever, and tropical dysentery, have been veritable scourges to the inhabitants of the low latitudes. By many the constant heat and humidity are considered to be insuperable obstacles to the maintenance of mental and physical vigor. Nevertheless, there is a growing optimism that modern hygiene and sanitation, together with electrical refrigeration and the creation of artificial indoor climates, may greatly reduce the hazards and discomforts associated with living in a tropical climate.

But if the rainforest provides a bountiful climate for plant growth, its low-grade residual soils, on the other hand, offer a serious counterbalance and make the growth of crops, other than the bush and tree crops with deeper roots, difficult. The strong leaching effects of the abundant and warm rains continuing throughout the entire year leave the soil deficient in mineral plant foods and in organic material. A very few years of cropping is sufficient to exhaust the topsoil so that the native agriculturist is forced to migrate or at least to shift his fields.

Like the climate, the vegetation resource is abundant, at least as far as quantity is concerned. No other climate produces such a dense growth of large trees. To the agricultural settler who is obliged to clear the land, this forest is much more of a handicap than a resource. On the other hand, no other of the earth's forest regions provides such a storehouse of wood and lumber, although the exploitation of this resource is associated with many obstacles.

Unoccupied lands are plentiful in the tropical rainforest regions, but the value of these areas for future settlement is a fiercely debated question. The matter is far from settled, although there is more optimism at present relative to their future than at any other time. Of all the earth's extensive areas of meager population, there is more hope for colonization in the wet tropics than in either the high-latitude or the dry lands.

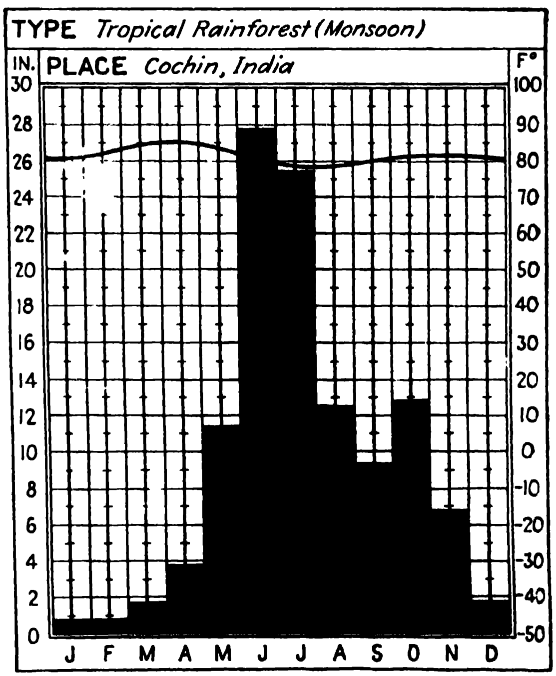

Fig. 87. Average monthly temperatures and precipitation amounts for a representative tropical rainforest station of the monsoon variety.

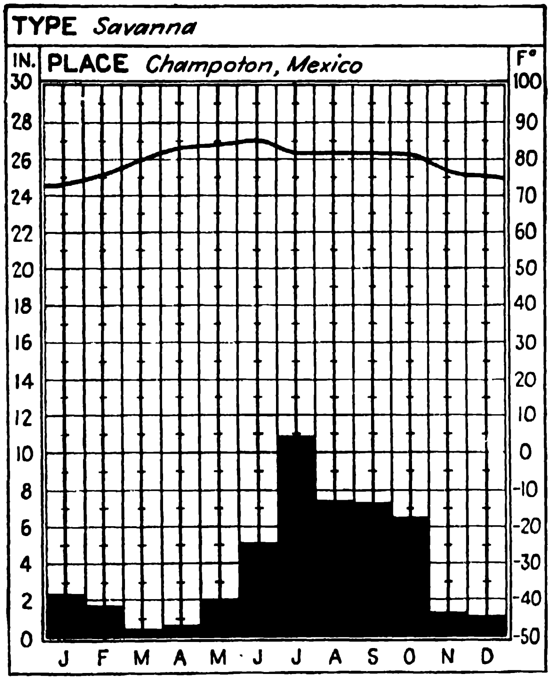

Fig. 88. Average monthly temperatures and precipitation amounts for a representative savanna station (19°21′N., 90°43′W.)

2. Tropical Savanna Climate (*Aw*)[1]

Savanna climate differs in two principal respects from tropical rainforest climate: (*a*) It usually has less precipitation; and (*b*) rainfall is unevenly distributed throughout the year, there being a distinctly wet and a distinctly dry season (Plate I, Figs. 57 and 88). These climatic contrasts result in the dense forest cover, typical of areas near the equator, being replaced by lighter, more open, tropical forests and tall grass in the savanna regions.

200. Location and Boundaries. On Fig. 82, showing the distribution and characteristic locations of types of climate on an ideal continent, savanna areas lie on the poleward and interior sides of the tropical rainforest climate and between it and the dry climates. In a general way the characteristic latitudinal location of the savannas is about 5+ to 15°±, and they may extend still farther poleward toward the windward, or eastern, side of the continent. This places them between the humid and relatively unstable rising air masses of the doldrums and equatorial margins of the trades on one hand, and the drier and more stable settling air masses of the subtropical high-pressure cells and poleward margins of the trades on the other. In other words, they are intermediate between a latitudinal zone of convergence and lifting and another of subsidence and divergence. With the northward and southward movements of the sun's rays these transition regions are encroached upon by both air masses or wind systems during the course of a year.

It becomes evident from a scrutiny of Plate III that many, if not most, of the large savanna areas do occupy the characteristic location described above and shown in Fig. 82. The Llanos of the Orinoco Valley (Colombia and Venezuela) and adjacent parts of the Guiana Highlands in northern South America, the Campos of Brazil, the Sudan and Veld of northern and southern Africa, respectively, and the tropical grasslands of northern Australia are all thus situated. In position, therefore, these savanna regions are often intermediate between the constantly wet and the constantly dry climates and are like each on their opposite margins. Not only are they intermediate in position, but they are likewise transitional in their wind, temperature, rainfall, and vegetation characteristics. On the rainforest or equatorward margins of the savannas rainfall is heavy, the dry season short, and temperature and vegetation closely resemble those of the rainforest. But as one travels poleward or interior toward the dry climates, the rainy season becomes shorter, temperature ranges are somewhat larger, and trees give way more and more to grasses.

TEMPERATURE

201. The temperature elements in savanna and tropical rainforest are not greatly unlike. Constantly high temperatures are still the rule, for the noon sun is never far from a vertical position, and days and nights change little in

[1] In the Köppen symbols *w* = dry season in winter or low-sun period: at least one month with less than 2.4 in. of rain.

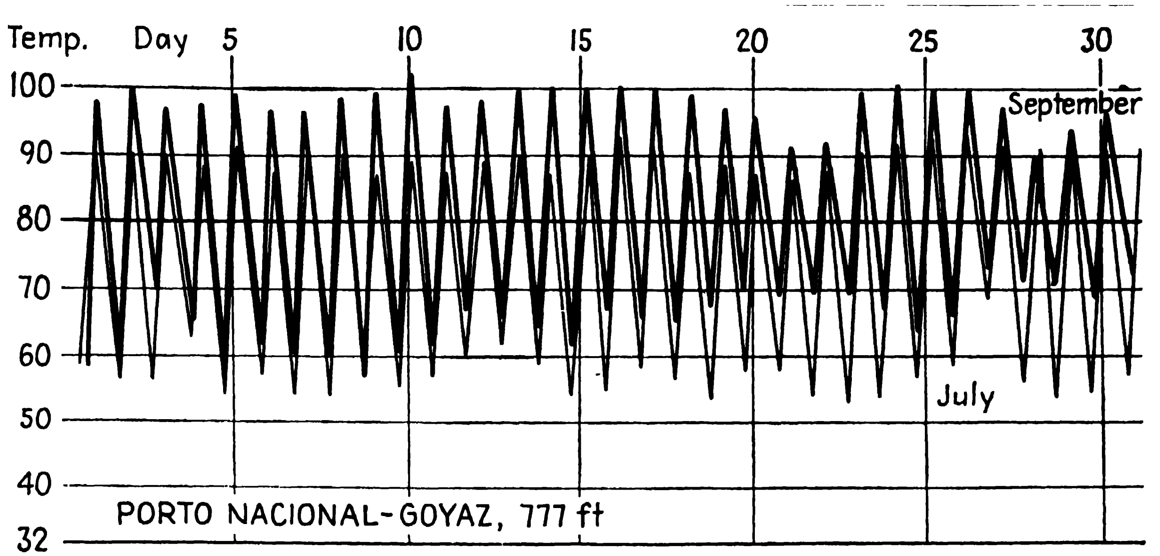

Fig. 89. Daily maximum and minimum temperatures for the extreme months at a representative savanna station in Brazil.

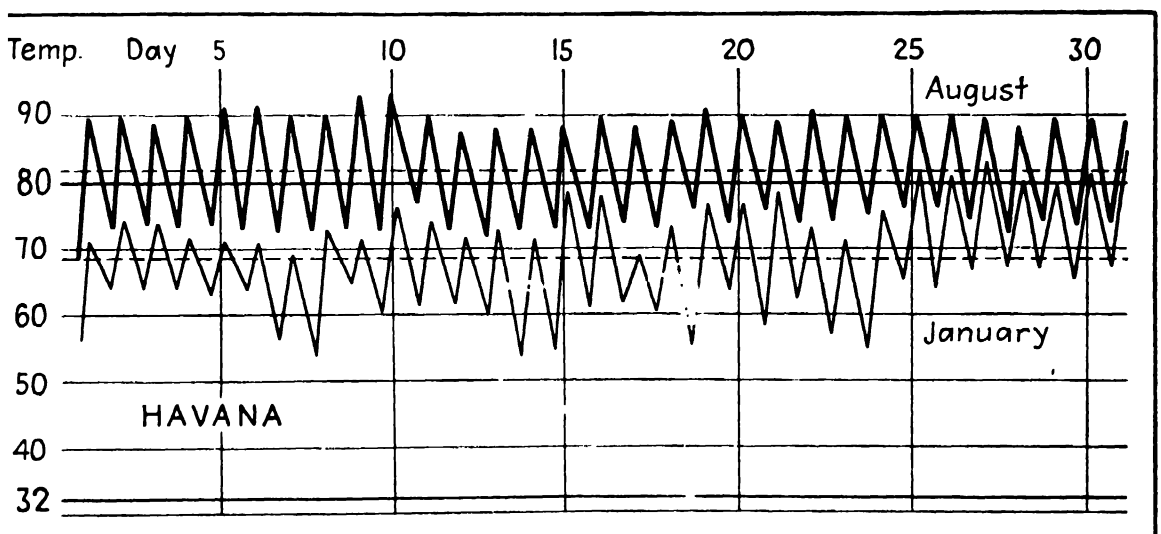

Fig. 90. Savanna station with a marine location.

length from one part of the year to another. In general, however, yearly ranges are somewhat greater (although still small) than in typical rainforest regions, usually over 5° but seldom exceeding 15° (Fig. 88). These larger ranges may result from the fact that the high-sun months are slightly hotter and the low-sun months are slightly cooler than is typical for regions nearer the equator.

It is significant that the hottest month or months many times do not coincide with the time of highest sun but usually precede it somewhat and thus occur before the height of the rainy period, when the more persistent cloud

cover and heavier precipitation tend to lower the temperature. Thus March, April, and possibly May are likely to be hotter than June or July, which are the rainiest periods for Northern Hemisphere savannas.

Climatic Data for Representative Tropical Savanna Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Timbo, French West Africa (10°40′N.)														
Temp.	72	76	81	80	77	73	72	72	72	73	72	71	74	9.7
Precip.	0.0	0.0	1.0	2.4	6.4	9.0	12.4	14.7	10.2	6.7	1.3	0.0	64.1	
Calcutta, India														
Temp.	65	70	79	85	86	85	83	82	83	80	72	65	78	21
Precip.	0.4	1.1	1.4	2.0	5.0	11.2	12.1	11.5	9.0	4.3	0.5	0.2	58.8	
Cuiabá, Brazil (15°30′S.)														
Temp.	81	81	81	80	78	75	76	78	82	82	82	81	80	6.6
Precip.	9.8	8.3	8.3	4.0	2.1	0.3	0.2	1.1	2.0	4.5	5.9	8.1	54.6	

PRECIPITATION

202. Amount of Rainfall. Since temperatures are not greatly different within the tropics, rainfall becomes the more critical element in setting apart the several climatic types of the low latitudes. Characteristically, the total amount of rainfall of the savanna is less than that of the tropical rainforest climate, 40 to 60 in. being more typical of the former. But since the savanna type usually occupies transitional belts between the constantly wet and the constantly dry climates, it naturally follows that there will be considerable contrast between the amount of rainfall on its two margins. As a general rule there is a decrease poleward.

203. Rainfall Regime. It is the seasonal distribution rather than the amount of precipitation, however, which chiefly distinguishes the two climates of the humid tropics, for the savanna type has a distinctly wet and a distinctly dry season. This contrast between the two types is principally due to their latitudinal locations, for although tropical rainforest is almost constantly within the convergence zone of doldrums and intertropical front, where there is a large-scale ascent of warm, humid, unstable air masses, savannas are on the *margins* of the doldrums and, therefore, in an intermediate position between them and the dry settling air masses of the subtropical high-pressure cells and the poleward margins of the trades.

NOTE. Although in the planetary system of winds *three* wind belts, doldrums, trades, and horse latitudes, are recognized as belonging to the tropics, only *two* general air masses with contrasting humidity and precipitation characteristics are so designated. These are the *tropical-stable (Ts) and the tropical-unstable (Tu)*. There is no distinct line of separation between the source regions of these two air masses, but usually it is drawn somewhere between latitudes 10 and 20, where the anticyclonic divergence and subsidence vanishes and where there is a distinct change in humidity, cloudiness, and precipitation. So drawn the line passes through the trades so as to include their equatorward portions with the doldrums to form the tropical-unstable air masses, and their poleward margins with the subtropical anticyclones to form the drier tropical-stable air masses where subsidence is prevalent.

The Sudan of northern Africa may be used as a concrete example to clarify further the mechanics of the savanna rainfall regime. As the sun's rays move northward from the equator after the spring equinox, their thermal effects cause pressure and wind belts to shift in the same direction, although lagging a month or two behind in time. As the equatorial or tropical-unstable air masses (doldrums and equatorial margins of trades) with heavy rains gradually creep northward, thunderstorms begin to appear in March or April over the Sudan, and the rainfall continues to increase in amount until July or even August, when the doldrums have reached their maximum northward migration. With the southward retreat of the tropical-unstable air masses, following the sun, the rains decline in amount, until by October or Novem-

ber the dry settling tropical-stable air masses (subtropical anticyclone and poleward margins of trades) are prevailing over the Sudan, and drought grips the land. The length of the wet and the dry seasons is variable, depending upon distance from the equator.

There is no abrupt boundary between the constantly wet and the wet-and-dry climates, but a very gradual transition from one to the other (Fig. 57). Thus on the equatorward margins of the savannas the rainy season persists for almost the entire year. In such locations there even may be a slight depression at the crest of the precipitation curve, this falling off of the rains occurring in the short interval of time between the northward and southward migrations of the doldrums (Fig. 57, Zungeru). The farther poleward one travels in the Sudan, the shorter is the period of doldrum control and the longer that of the drier settling air masses, so that the dry season increases in length while the wet period shrinks. For the sake of emphasis it bears repeating that the rainy season in the savannas closely coincides with the period of high sun and the presence of rising tropical-unstable air masses, whereas the dry season is identified with the period of low sun and drier settling tropical-stable air masses. Most emphatically, rainfall follows the sun. This rule holds for either hemisphere, although it should be kept in mind that December to February is the period of high sun (summer) south of the equator and June to August the period of low sun (winter). It is obvious, therefore, that when a Northern Hemisphere savanna is having its rainy season, a similar region south of the equator is experiencing drought, and vice versa.

204. Monsoon Savannas. In certain parts of southern and southeastern Asia, particularly in India, Burma, and French Indo-China, are savanna lands that do not have the characteristic location with respect to wind belts described above. Here, instead of lying between latitudinally migrating wet and dry air masses, the savannas are under the influence of monsoon winds and so experience nearly a complete reversal of wind direction within the year. In monsoon savannas the wet and dry seasons usually coincide with the periods of onshore and offshore winds, respectively. During the low-sun or dry period relatively dry stable continental air masses prevail. In the opposite season, at the time of high sun, there is an importation of warm humid air from over great expanses of tropical ocean. This is the rainy season. The onshore monsoon is effective in producing a wet season, chiefly because it transports a tremendous amount of warm, humid, unstable air in over the land, providing thereby an atmospheric environment favorable for the growth of storms and a large reservoir of water vapor from which thunderstorms, tropical lows, typhoons, or highland barriers acting as lifting agents may produce abundant rainfall. Where the onshore monsoon is forced to ascend over coastal mountains, rainfall is usually so abundant that, in spite of seasonal periodicity, monsoonal rainforest climate (*Am*), instead of savanna climate, is the result. Where coasts are less elevated, or the region has an interior location so that rainfall is lower, savanna climate is more likely to prevail.

205. Seasonal Weather. During its *rainy* season the weather of savanna climate closely resembles that of tropical rainforest at its worst. This period usually is ushered in and out by violent thunderstorms and severe squall winds, which in Africa are called tornadoes. In these transition periods the weather is very trying, "violent short deluges of rain and intensely hot sunshine alternating." During the height of the rains violent thunderstorms appear to be less frequent than they are at the transition periods, while on the other hand heavy, long-continued, and more general rains reach their maximum at that time. These latter probably originate in weak tropical lows.

In the low sun, or *dry*, season the weather is like that of the deserts. The humidity becomes very low so that the skin is parched and cracked. In spite of the aridity, the dry season is welcomed after the humid, oppressive heat of the rainy period. An occasional shower may occur during the months of drought, the number depending upon which margin of the savannas is being

considered. On the dry margin the period of absolute drought may be of several months' duration, while on the rainy margin, where it makes contact with tropical rainforest climate, there may be no month absolutely without rain. *The fact should never be lost sight of that none of these boundaries is sharp, there being very gradual transitions from one type to another.* During the dry season the savanna landscape is parched and brown, the trees lose their leaves, the rivers become low, the soil cracks, and all nature appears dormant. Smoke from grass fires and dust fill the air, so that visibility is usually low.

The following quotation[1] is a description of the seasonal weather and related landscape changes in a savanna region. It should be emphasized, in order to avoid confusion, that the region described is Zambezia, Africa, which is *south* of the equator. As a result of Southern Hemisphere location, the months included within the several seasons are exactly opposite from what they are in regions north of the equator.

The winter months, or dry season, extend, with a slight variation, from April to November. They are, as I have said, pleasant and healthy in the extreme. Now the traveller and hunter of big game make their appearance; the deciduous trees are leafless; the grasses dry, yellow, and ready for the chance spark or deliberate act which, with the aid of a steady breeze, will turn vast expanses of golden grasslands into so many hideous, bare deserts of heat-tremulous black. All nature seems to be at a standstill, hibernating. The rivers are low. Where, but a few short months since, wide, watery expanses rushed headlong toward the sea . . . there now remain but tranquil, placid channels, flowing smilingly at the bottom of steep, cliff-like banks. . . .

With October the heat becomes very great. Vast belts of electrically charged, yellowish clouds, with cumulus, rounded extremities, begin to gather and at the close of day are seen to be flickering in their murky centres with a menacing tremor of constant lightning. This may go on for a week or more, and then Nature arises like a strong man in anger and looses the long pent-up voice of the thunder and the irresistible torrents of the early rains. The first manifestation may come at evening and is a soul-moving display of natural force. . . .

After such a disturbance as the one I have just described, rain is fairly continuous for some time, and the effect of this copious irrigation makes itself felt in every branch of animal and vegetable life. Within a few days the change is startling; the paths and roadways choke themselves with a rich clothing of newly sprung grasses, whilst the trees, the extremities of whose twigs and branches have been visibly swelling, now leap into leaf and blossom. The mosses, which for months past have looked like dry, bedraggled, colourless rags, regain once more their vivid, tender green. Now the forest throws off its puritanical greyness and, with an activity and rapidity beyond belief, decks itself in flowers of a thousand gorgeous shades of colour, from chrome-yellow and purple to grateful mauve.

The birds now put on their finest feathers, the animals appear in their brightest hues. Colour and warmth run riot in the brilliantly clear air now washed clean from the mist and smoke which for so many months have obscured it. The clear verdant green of rapid-springing grasses and opening fronds clothes the landscape, and the distant peaks of the mountains lose their pale, bluey-grey haziness and stand boldly out in the light of the sun. The months succeed each other, bringing with them new and strange beauties, for summer is now at its height, and trees and flowers at their most perfect period. . . . April comes, and suddenly Nature holds her hand. The swollen rivers and inundated plains shake themselves free from the redundant waters. The grasses have now reached a formidable height. The rains now cease, and the land begins to dry up. Rich greens turn to copper, and brown, and yellow, and little by little, with the advent of May, the winter returns with its sober greyness.

206. Rainfall Reliability. Not only is savanna rainfall less in total amount, and more periodic in its distribution throughout the year, as compared with tropical rainforest, but it is likewise less reliable, there being wider fluctuation in the amounts from year to year. One year may bring such an abundance of rain as to flood the fields, rot the crops, and increase the depredations of injurious insects and fungi, while the following year may witness even more severe losses from drought. In northern Australia the average rainfall variation from the

[1] R. C. F. Maugham. "Zambezia." Pp. 383–388. John Murray, London, 1910.

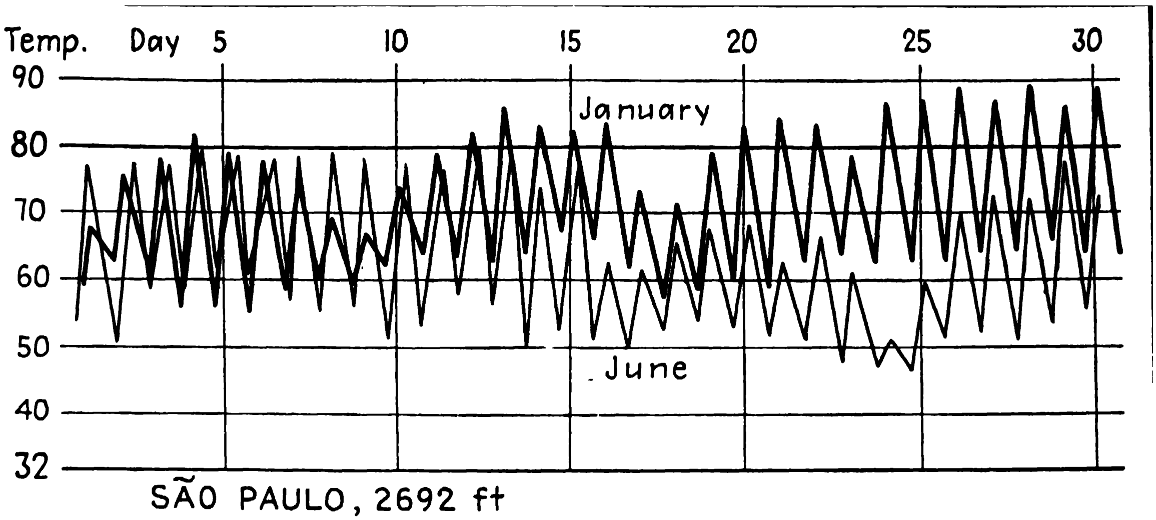

Fig. 91. Upland-savanna station on the Brazilian plateau.

normal is as much as 25 per cent (Fig. 92). The undependable rainfall seriously reduces the potentialities of the savanna regions for supporting human life. In such densely populated savannas as India, where even in normal years the food supply may scarcely be sufficient, a bad drought or flood year has in the past often resulted in serious famine. Because of the relatively meager populations of most of the savanna lands, one hears less of their distress resulting from variable rainfall, but that there is great misery resulting from droughts and floods cannot be doubted.

UPLAND SAVANNA (*Cw*)[1]

207. In tropical latitudes on several continents, but especially Africa and South America, there are extensive upland areas, possessed of many of the normal savanna characteristics but differing chiefly in their lower temperatures (Fig. 91). Some of the upland savannas, such as those of eastern Brazil and of eastern Africa, are among the best developed, for the lower temperatures make them more attractive to agricultural settlers. These savannas are included within the general savanna type but on Plate III are set apart from the more standard lowland variety by a light stippling. (For climatic modifications imposed by altitude, see Chap. 11.)

208. Resource Potentialities of the Savanna Realm. Tropical savanna climate, including upland savannas, characterizes close to 15 per cent of the earth's land area. Like the tropical rainforest, the savanna lands do not support a percentage of the world's population proportionate to their area. On a map showing the distribution of the earth's inhabitants, most of the savanna areas are conspicuous because of their dearth of people. This is especially true of the New World savannas and those of Australia. Peninsular India is the most striking exception, for there human life is abundant. Portions of the African Sudan and of the upland savannas of east Africa are somewhat intermediate in their population densities.

Although temperatures are constantly high in savanna climate, the fact that there is a dormant season imposed by drought considerably reduces the productiveness of savanna as compared with rainforest climate. The smaller

[1] According to the Köppen classification, *Cw* climates appear in two characteristic locations: (*a*) tropical-savanna uplands, where because of altitude the temperature is lowered below that of the surrounding lowlands (*Aw*); and (*b*) mild subtropical monsoon lands such as exist in southern China. It is the first group that is here being classified as the subtype *upland savanna*. The other group is included within the humid subtropical climates of the middle latitudes.

total amount of precipitation, and its variability as well, emphasizes this contrast still further. Reflecting the reduced climatic energy, the vegetation cover is one of tall coarse grasses and of open forest with grass instead of a dense evergreen forest such as characterizes the rainforest climate. Much of the savanna woodland is of little value commercially, while the grasses are too tall, coarse, and unnutritious to support an important grazing industry. To the native agriculturist the tough grass sod offers a more formidable obstacle than does the luxuriant rainforest. Little is known about soils of savanna regions, but as a general rule they appear to be leached and infertile. As in most regions of infertile or difficult soils, the fresh, young, unleached alluvial surfaces are the most attractive sites for cultivation.

CHAPTER 8: *The Dry Climates (B)*

209. Definition and Boundaries of Dry Climates. The essential feature of a dry climate is that potential evaporation shall exceed precipitation.[1] As a result of rainfall deficiency there is no surplus of water with which to maintain a constant ground-water supply, so that permanent streams cannot originate within such areas. It may be possible, however, for streams to cross them, as do the Nile and the Colorado, for instance, provided they have their sources in more humid regions.

If the above definition of a dry climate, *viz.*, one in which potential evaporation exceeds precipitation, is accepted, then, since evaporation varies greatly in different parts of the earth, it follows that no specific amount of rainfall can be used to bound dry climates over the world as a whole. Potential evaporation is greater in warm than in cold regions, so that while 25 in. of precipitation may be effective in producing a humid landscape with forests in cool northwestern Europe, the same amount falling in the hot tropics results in semiarid conditions. Moreover, if a large amount of the annual precipitation in subtropical climates comes in the warmer months when evaporation is higher, more is lost through evaporation and less is available for plant growth. Thus barley is grown in parts of southern California where the rainfall is not much more than 10 in. and the climate is arid or semiarid. This is possible, however, because the meager precipitation is concentrated in the cool season when evaporation is at a minimum. Its effectiveness for plant growth is therefore great.

[1] Rate of evaporation may be measured by freely exposing to the weather an open vessel containing water and noting the drop in the level of the water surface.

210. Desert and Steppe. Two subdivisions of dry climates are commonly recognized: (*a*) the arid, or desert, type and (*b*) the semiarid, or steppe, type. In general, the steppe is a transitional belt surrounding the real desert and separating it from the humid climates beyond. The boundary between arid and semiarid climates is a relatively arbitrary one, but by Köppen it is defined as one-half the amount separating steppe from humid climates. For example, if in a particular region 19 in. of rainfall marks the outer, or humid, boundary of dry climates in general, then $9\frac{1}{2}$ in. may be taken as the boundary between steppe and desert for that same region (Fig. 82).

211. Temperature. Since dry climates exist in a wide variety of latitudes and continental locations, few significant general comments on their annual temperatures can be made. On the whole, however, because of characteristic interior and leeward locations on the continents, they tend to be severe for their latitude, having relatively extreme seasonal temperatures and consequently large annual ranges.

More marked, however, are the large daily ranges, clear, cloudless skies, and relatively low humidity permitting an abundance of solar energy to reach the earth by day but likewise allowing a rapid loss of earth energy at night. Large diurnal ranges in deserts also are associated with the meager vegetation cover, which permits the dry barren surface to become intensely heated by day. It is a physical law that the higher the temperature of a body, the more rapid is its loss of heat by radiation and consequently the more rapid its reduction in temperature.[2] Deserts, therefore, not only acquire,

[2] The amount of heat radiated by a body is directly

but likewise lose, heat rapidly. In humid regions with a greater amount of vegetation, more of the solar radiation is consumed in evaporating moisture from plant surfaces and from the damp earth, so that extreme temperatures, like those of deserts, are less likely. Where vegetation is abundant, water vapor is likely to be also, and night cooling is consequently retarded.

212. Precipitation and Humidity. Rainfall in the dry climates is always meager. In addition it is extremely variable from year to year so that the average is not to be depended upon (Fig. 92). Significantly, also, there are more years when rainfall is below the average than above, for it is the occasional humid year which tends to lift the average. It is a general rule, worthy of memorization, that dependability of precipitation usually decreases with decreasing amount. Two handicaps, therefore, (*a*) meagerness and (*b*) unreliability of rainfall, seem to go together. No part of the earth, so far as is known, is absolutely rainless, although at Arica, in northern Chile, the average yearly rainfall over a period of 17 years was only 0.02 in. During the whole 17 years there were only three showers heavy enough to be measured.

Relative humidity is (with a few exceptions) low in the dry climates, 12 to 30 per cent being usual for midday hours. Conversely, evaporation is extremely high. Absolute humidity, on the other hand, is by no means always low, for hot desert air usually contains a considerable quantity of water vapor, even though it may be far from being saturated. The amount of sunshine is great, and cloudiness small. Direct as well as reflected sunlight from the bare, light-colored earth is blinding in its intensity.

213. Winds. Dry regions are inclined to be windy places, there being little friction of the moving air with the lowly and sparse vegetation cover. In this respect they are like the oceans. Moreover, the rapid daytime heating of the lower air over deserts leads to convectional overturning, this interchange of lower and upper air tending to accelerate the horizontal surface currents during warm hours when convection is at a maximum. "In the desert the wind is almost the only element of life and movement in the domain of death and immobility. A journey in the desert is a continuous strife against the wind charged with sand and, in moments of crisis, a painful physical struggle." (Gautier.) Nights are inclined to be much quieter. Because of the strong and persistent winds, desert air is often murky with fine dust which fills the eyes, nose, and throat, causing serious discomfort. Much of this dust is carried beyond the desert margins to form the loess deposits of bordering regions. The heavier, wind-driven rock particles, traveling close to the surface, are the principal tool of the wind in sculpturing desert landforms.

In the classification of climates here employed, two great divisions of dry climates, based upon temperature contrasts, are recognized: (*a*) the dry climates of the low latitudes, or the *hot* steppes and deserts; and (*b*) the dry climates of the middle latitudes, or the *cold* (in winter) steppes and deserts.[1] Not infrequently the low- and middle-latitude dry climates are continuous with each other, the latter occupying the far interiors of the middle-latitude continents, and the former the interiors and western (leeward) margins of land masses in the latitudes of the subtropical highs and where cool ocean currents parallel the coasts.

3. Low-latitude Dry Climates (*BWh* and *BSh*)[2]

214. Location. The heart of the tropical dry climates (Fig. 82) is in the vicinity of latitudes 20 or 25°N. and S., with the average positions of their extreme margins at approxi-

proportional to the fourth power of its absolute temperature.

[1] Köppen uses the mean annual isotherm of 64.4° (18°C.) as the boundary between the two principal latitudinal subdivisions of dry climates. For North America at least, the January isotherm of 32° appears to be a better boundary between the hot and the cold dry climates.

[2] In the Köppen symbols, *W* = desert (*Wüste*); *S* = steppe; *h* = hot (*heiss*): annual temperature over 64.4° (18°C.).

another occasion 2.5 in. of rain fell in a single shower.

217. Desert Downpours. General, widespread rains are almost unknown over large parts of the hot deserts, most of the precipitation coming in violent convectional showers which cover no very extensive area. Seven single storms brought nearly one-quarter of the total rain (30.7 in.) that fell at Helwan in the Egyptian Sahara in the 20-year period 1904–1924. These sudden and heavy downpours may be disastrous in their effects, causing more damage than they do good. The wadis, entirely without water during most of the year, may become torrents of muddy water filled with much debris after one of these flooding rains. Settlements suffer; roads, bridges, and railways may be injured; and irrigation systems are often clogged with debris after a serious desert flood. Because of the violence of tropical desert rains and the sparseness of the vegetation cover, temporary local runoff is excessive, and consequently less of the total fall becomes effective for vegetation or for the crops of the oasis farmer. This "dash" character of hot-desert showers, plus their local nature and their erratic seasonal distribution, makes them of little direct use for agriculture, so that no immediate dependence is placed upon them as a source of water. Much of the precipitation that reaches the earth is quickly evaporated by the hot, dry, desert air, but some sinks in to replenish the underground water which appears at the surface in the form of springs or artesian flows. On the *poleward* margins of low-latitude deserts there are occasional widespread rains of a less violent nature. These are usually associated with the fronts of middle-latitude cyclones and are largely confined to the low-sun period.

218. Cloudiness and Sunshine. Skies are prevailingly clear in the low-latitude deserts so that sunshine is abundant. In the Sonora desert of the United States and Mexico 75 ± per cent of the possible sunshine is experienced in winter, and 90 ± per cent in the other seasons. Over much of the Sahara, December and January have a cloudiness of only 1/10, while from June to October it drops to about 1/30. The pitiless glare of sunlight in the tropical deserts is such an essential characteristic of their landscapes that the occasional dark or rainy day, being so unusual, is said to be depressing. Strong surface heating, due to the intense insolation and the nearly bare ground, must give rise to vigorous convectional currents, but the whole mass of air is too warm and has too low a relative humidity to allow these rising air currents, except infrequently, to reach condensation level and produce "thunderheads." Dark cumulo-nimbus clouds do form occasionally, sometimes accompanied by thunder and lightning, but the streamers of rain that can be seen descending from them usually are evaporated in the arid atmosphere before they reach the earth. But even though the air may be *physiologically dry* and have unusual evaporating power, there is usually a moderate amount of moisture in the atmosphere. Thus the air at Yuma, Ariz., contains nearly as much moisture in July, and double as much in January, as does that at Madison, Wis., in the same months, although the relative humidity is only one-half to two-thirds as great in either season.

219. *Evaporation*, due to the high temperature and low relative humidity, is excessive, often being twenty or more times the precipitation. At Yuma the average evaporation during the hot months is 55 in., while the average rainfall during the same period is not quite 1 in. Relative humidities as low as 2 per cent, with temperatures of over 100°, have been recorded in the Egyptian Sahara. It was the excessively dry air which allowed the Egyptians to mummify their dead.

Temperature

220. Annual and Diurnal Temperatures. Annual ranges of temperature in the low-latitude deserts are larger than in any other type of climate within the tropics, 20 to 30° being usual (Fig. 93). Aswân, in the Sahara, has mean temperatures of 61° in January and 95° in July, resulting in an annual range of 34°. Such ranges, which even exceed those of some middle-latitude climates, reflect not only the

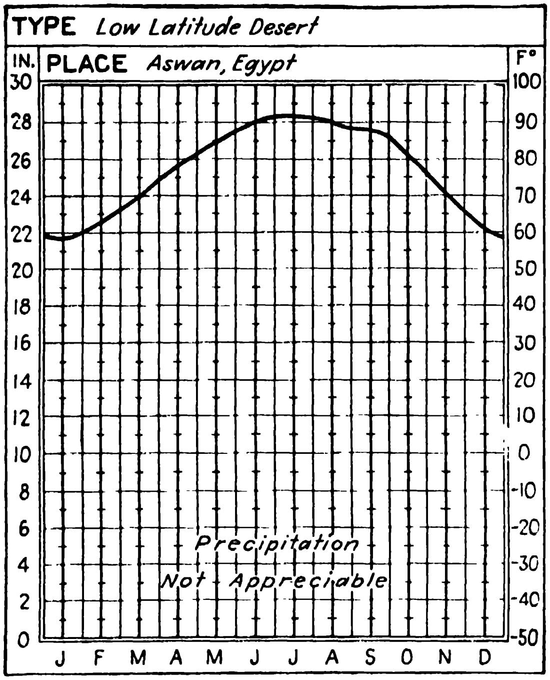

Fig. 93

clear skies, bare earth, and low humidity but also the higher latitudes of the deserts, and their somewhat greater extremes of insolation, as compared with most of the humid tropics. It should be emphasized that it is the excessive "summer" heat, rather than the "winter" cold, which leads to the marked differences between the seasons. Daily ranges average 25 to 45° and in rare instances even reach 60 or 70°. The same conditions that make for relatively large temperature differences between the extreme months are likewise conducive to wide differences within 24 hr. On Dec. 25, 1878, at Bir Milrha, south of Tripoli in the Sahara, a minimum temperature of 31° and a maximum of 99° were recorded on the same day.

221. Seasonal Temperatures. During the high-sun period scorching, desiccating heat prevails. Hot-month temperatures average between 85 and 95° (Yuma, 91°; Timbuktu, 94.5°; Nullagine, Australia, 89.8°), and midday readings of 105 to 110° are common at this season. At Yuma, in one summer the daily maxima exceeded 100° for 80 consecutive days, except for one day (Fig. 94). At this time of the year, although the lower night temperatures are a distinct relief by contrast with the days, they are by no means cool. At Phoenix, Ariz., the midsummer daily maxima usually exceed 100°, and the minima are close to 75 or 76°. At Azizia, 25 miles south of Tripoli, 136.4° has been recorded, this being the highest air temperature in the shade ever registered under standard conditions. The highest official air temperature ever recorded in the United States is 134°, in Death Valley in the California desert.

During the period of low sun the days still are warm, with the daily maxima usually averaging 60 to 70° and occasionally reaching 80° (Fig. 94). Nights are distinctly chilly at this season, with the average minima in the neighborhood of 40°±. Occasionally light frosts are experienced in these tropical deserts, and heavy night dews are frequent.

Sun very much controls the weather in tropical deserts so that succeeding days are very similar (see Fig. 94). On their poleward margins there are occasional invasions of polar air with associated fronts that bring "spells of weather" especially in winter. Figure 94 showing the daily march of temperature clearly reveals these nondiurnal oscillations of the temperature belt.

THE COOL WESTERN LITTORALS (*BWn*)

222. Temperature. The usual characteristics of tropical deserts—high temperatures,

Climatic Data for Representative Stations in Low-latitude Deserts

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Jacobabad, India														
Temp.	57	62	75	86	92	98	95	92	89	79	68	59	79	41
Precip.	0.3	0.3	0.3	0.2	0.1	0.2	1.0	1.1	0.3	0.0	0.1	0.1	4.0	
William Creek, Australia														
Temp	83	83	76	67	59	54	52	56	62	70	77	81	68	30.5
Precip.	0.5	0.4	0.8	0.4	0.4	0.7	0.3	0.3	0.4	0.3	0.4	0.3	5.4	

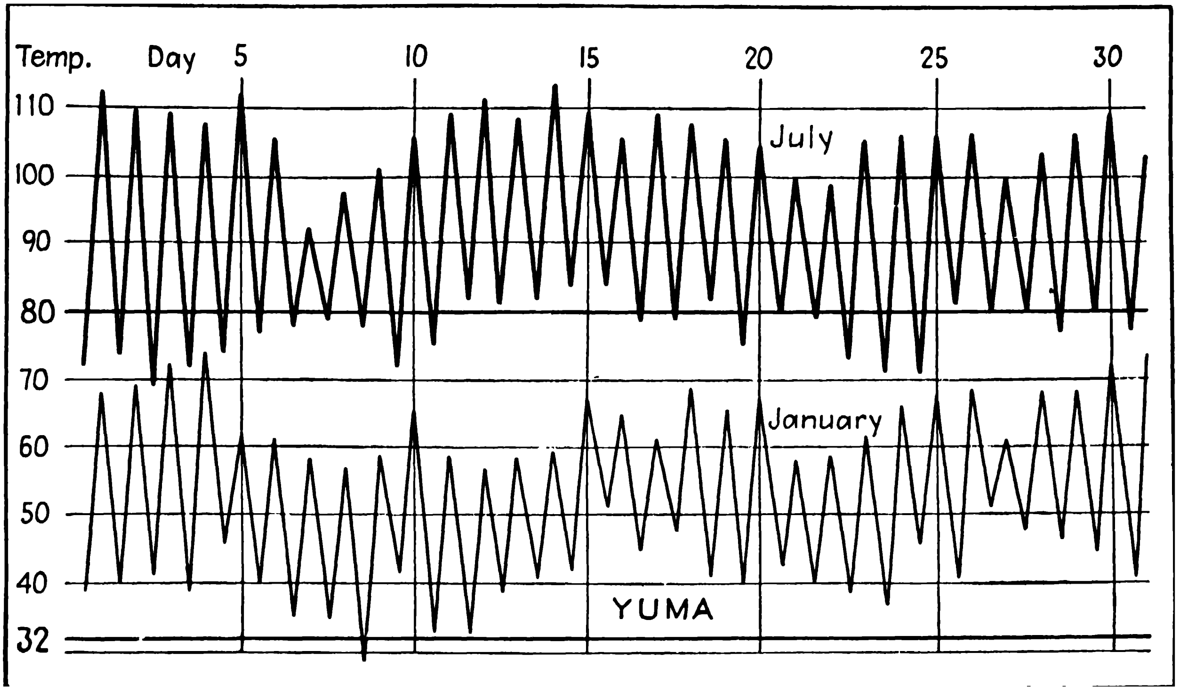

Fig. 94. A representative station in a low-latitude desert.

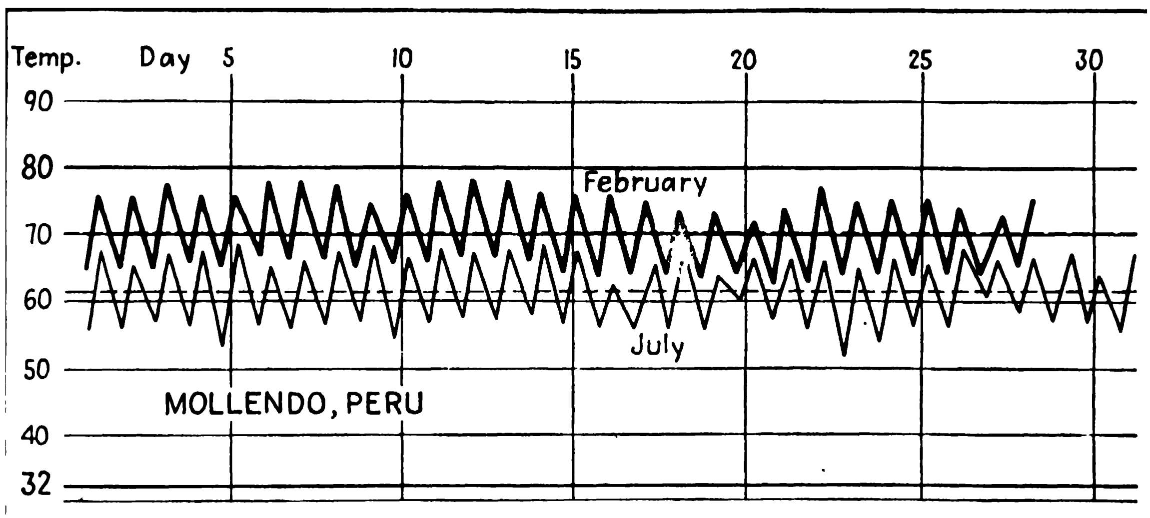

Fig. 95. A coastal station in a low-latitude desert paralleled by a cool ocean current. Note the relatively low temperatures and the small daily ranges.

low relative humidity, and little cloud—are modified to a considerable degree along the littorals (usually western) of several of the low-latitude deserts, where cool ocean currents parallel the coasts (Fig. 95). The presence of cool currents is especially marked along the desert coasts of Peru and northern Chile, and the Kalahari in southwestern Africa, but their influence is also felt along the Atlantic coasts of the Moroccan Sahara, Somaliland in eastern Africa, northwestern Mexico, and a number of other places as well. The land margins adjacent

to the cool waters are themselves unusually cool, with temperatures 10° or more lower than normal for the latitude. Thus Callao, on the Peruvian coast, has an annual temperature of only 67°, and Mollendo 65°, while Bahia on the east coast of Brazil, in a similar latitude, averages 77°. During the hottest month the temperature at Callao is only 71° (similar to July at Madison, Wis.), while during the coldest it is 62.5°. This annual range of only 8.5° is extraordinarily small for a desert, but it needs to be emphasized that it is principally the result of the unusually cool summer.

223. Precipitation and Fog. Rainfall along these cool tropical coasts is extremely low (2.3 in. at Port Nolloth in southwestern Africa, 1.2 in. at Callao in Peru), even lower than in the great interior continental deserts, and the drought conditions may extend to within a few degrees of the equator. The intensified aridity is the result of two phenomena: (*a*) these tropical western littorals are under the influence of the eastern ends of the oceanic subtropical high-pressure cells with their subsiding and drying air, and (*b*) they are paralleled by cool ocean currents. As warm air from over the tropical ocean proper drifts landward over the cool waters closer to the coast, the mT air is chilled at the base, its lapse rate is thereby decreased, and its stability increased, so that precipitation is very unlikely.

Peculiarly enough, however, in spite of the fact that precipitation is very meager, there is an abundance of low stratus cloud so that skies are gray and the brilliant sunshine of normal deserts is uncommon. The relative humidity is also very high, and fog and even mist are characteristic phenomena over the cool ocean current and the adjacent coasts. At Cape Juby in northwest Africa relative humidity is 91 per cent in July and 82 per cent in January. The foggiest belt is several miles offshore, and the condition is brought to the land by winds from the sea. As the cool, foggy air moves in over the warmer land, the fog is quickly evaporated and rarely extends far inland. At Swakopmund (Southwest Africa) fog is recorded on 150 days in the year. Sea breezes along these coasts, intensified by the cool ocean water offshore, are extraordinarily strong.

In Peru the heavy fog, or "wet mist," is sufficient to make for a meager showing of vegetation on the coastal hills. Darwin, in his book "The Voyage of the Beagle," describes these Peruvian mists as follows:

> A dull heavy bank of clouds constantly hung over the land, so that during the first sixteen days I had only one view of the Cordillera behind Lima. It is almost become a proverb that rain never falls in the lower part of Peru. Yet this can hardly be considered correct; for during almost every day of our visit there was a thick drizzling mist which was sufficient to make the streets muddy and one's clothes damp; this the people are pleased to call "Peruvian dew."

In occasional years these desert west coasts, more especially the sections closest to the equator, may have their cool desert climates terminated abruptly and the high temperatures and heavy rainfall of the tropical rainforest climate established in their place. These climatic reversals are the result of the weakening or poleward displacement of the high-pressure cell and a substitution of warm water for the prevailingly cool current. The temporary, abnormal rainforest conditions are quickly ended, with the reestablishment of the high-pressure cell and the cool ocean current.

Climatic Data for a Representative Desert Station on a Cool-water Coast

Lima, Peru

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	71	73	73	70	66	62	61	61	61	62	66	70	66	12.8
Precip.	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.5	0.1	0.0	0.0	1.8	

3*b*. LOW-LATITUDE STEPPE (*BSh*)

224. Location. It is again necessary to emphasize the fact that low-latitude steppe climates characteristically surround the low-latitude deserts, except possibly on their western

sides (Fig. 82), and are, therefore, transition belts between them and the humid climates both to the north and to the south. Because they are less at the heart, and more on the margins of the dry, settling tropical air masses associated with subtropical highs and trades, and are, therefore, one step closer to the humid climates than are the deserts, the steppe lands are encroached upon for a short period of the year by rain-bearing winds and their associated storms. It is this brief period of seasonal rains which causes them, although still a dry climate, to be semiarid rather than arid.

Precipitation and Humidity

225. Precipitation Meager and Erratic. Rainfall in the steppes, like that in the deserts, is not only meager but also variable and undependable (Fig. 92). This characteristic is perhaps even more dangerous in the semiarid than in the arid lands, for in the latter precipitation is never enough to tempt settlers to make agricultural conquest other than at oases, while occasional humid years in the steppe may be sufficiently wet to lure inexperienced persons to attempt it. But a few humid years are invariably followed by more dry ones, and with these comes disaster to settlers who have ventured too far beyond the safety line. Only where irrigation water supplements the normal rainfall is agriculture safe, so that the grazing of animals becomes a more widespread form of land use.

226. *Steppes with Low-sun Rainfall.*[1] Those belts of steppe lying on the poleward sides of tropical deserts, and usually in fairly close proximity to Mediterranean climate, have nearly all their rain in the cool seasons. Like the Mediterranean climates on whose margins they lie, they receive their rain from fronts associated with middle-latitude cyclones which because of sun migration characteristically travel more equatorward routes in winter than in summer. During most of the year, however, these steppes are dominated by dry settling air masses associated with the subtropical anticyclones. Because rainfall is concentrated in the cool season, evaporation is less, and consequently the small amount that falls is relatively effective for plant growth. Moreover variability is not so great as in those steppes having a high-sun rainfall maximum. In steppe lands with a low-sun rainfall *spells of weather* associated with the air masses and fronts of passing cyclonic storms are not unusual in the winter season. Not only cloud and rainfall, but changes in temperature as well, are involved. In spite of winter being the rainiest season, it is nevertheless prevailingly sunny, the precipitation coming in showers of rather short duration. Occasional gray, overcast days with rain do occur, however.

Climatic Data for a Representative Low-latitude Steppe Station with Low-sun Rainfall

Bengasi, Tripoli

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	55	57	63	66	72	75	78	79	78	75	66	59	69	24
Precip.	3.7	1.8	0.7	0.1	0.1	0.0	0.0	0.0	0.1	0.3	2.1	3.1	11.9	

227. *Steppes with High-sun Rainfall.*[2] Those tropical steppe lands lying on the equatorward margins of the deserts, and therefore between them and the savannas, are likely to have a very brief period of relatively heavy rains at the time of high sun, when unstable *mTu* air and the I.T.F. are farthest poleward. Rainfall periodicity is like that of the savannas except that the dry season is longer and the total precipitation less. Since the rainfall arrives in the hot season less of it is effective for vegetation, and consequently these steppes bordering the savannas usually are characterized by a greater total rainfall than are their poleward counterparts described above (226). Rainfall variability is also greater. Temperatures are not greatly different from those of the adjacent desert.

[1] Köppen subtype *BShs*, in which *s* stands for summer drought.

[2] Köppen subtype *BShw*, in which *w* stands for winter drought.

Climatic Data for a Representative Low-latitude Steppe Station with High-sun Rainfall

Kayes, French West Africa

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Temp.	77	81	89	94	96	91	84	82	82	85	83	77	85	19.2
Precip.	0.0	0.0	0.0	0.0	0.6	3.9	8.3	8.3	5.6	1.9	0.3	0.2	29.1	

4. Middle-latitude Dry Climates (*BWk* and *BSk*) [1]

228. Location. The middle-latitude steppes and deserts are not primarily the result of location within particular wind belts or along cool-water coasts, as are those of low latitudes. Dry climates in the middle latitudes usually are found in the deep interiors of the great continents, far from the oceans, which are the principal sources of the atmosphere's water vapor (Fig. 82, Plate III). Asia, the greatest land mass in middle latitudes, has the largest area of dry climates, and North America is next in order. Further intensifying the aridity of these deep interiors is the fact that they are largely surrounded by mountain or plateau barriers that block the entrance of humid maritime air masses. Where high mountains closely parallel a coast as in western North America, arid climates approach close to the sea.

Although tropical deserts characteristically extend down to the ocean margins on the leeward (western) sides of continents, the leeward (eastern) sides of land masses in the westerlies are far from dry. Witness, for example, eastern North America and Asia. This shifting of middle-latitude dry climates interior from the leeward coasts is associated with the presence of monsoons and cyclonic storms along the eastern sides of land masses in the westerlies. Owing to an unusual combination of circumstances, dry climates do reach the east coast in Patagonia (Argentina), but this is the exception. There the land mass is so narrow that all of it lies in the rain shadow of the Andes, where descending currents make for drought conditions. This same small land mass precludes monsoon development. The cool Falkland Current lying offshore likewise induces aridity, while the principal frontal zones are to the north and south of the area in question. Moreover, those storms that do cross the high Andes temporarily are so disrupted that they are unable to bring much rain to the Patagonian uplands. With the exception of South America, none of the other Southern Hemisphere continents extends into sufficiently high latitudes to permit the development of very extensive middle-latitude steppes and deserts.

[1] In the Köppen symbol *k* = cold (*kalt*): average annual temperature below 64.4° (18°C.).

229. Temperature. Although dry continental climates of middle latitudes duplicate the arid and semiarid climates of the tropics in their meager and undependable rainfall, they differ from them in having a season of severe cold, which is of course absent in the low latitudes (Fig. 96). On the other hand, they are like the *humid* continental climates of comparable latitudes in their temperature and weather characteristics but they are unlike them in that they receive less rainfall.

The interior locations of most middle-latitude dry climates assure them of having relatively severe seasonal temperatures and consequently large annual ranges. Because they have such a wide latitudinal spread (15 or 20° in both North America and Asia) it is difficult to speak of *typical* temperature conditions, for they are very different on their equatorward and poleward margins. Yet for any given latitude temperatures are severe. Summers are inclined to be warm or even hot, and winters are correspondingly cold. The temperature at Tehran, Iran, at 36°N. ranges from 34° in January to 85° in July, whereas for Urga, Mongolia, at 48°N. the comparable figures are −16 and 63°. Diurnal ranges are inclined to be large and for the same reasons as noted in the discussion on tropical steppes and deserts (Figs. 96 and 97).

230. Precipitation. Locational reasons for the aridity of middle-latitude dry climates have been given in Art. 228. An additional

summer temperatures being unusually low. Winters are likewise mild, considering the latitude. Thus Santa Cruz at 50°S. has a January (hottest month) temperature of only 59°, while in July it is 35°.

4*b*. MIDDLE-LATITUDE STEPPES (*BSk*)

233. Middle-latitude steppes, like their counterparts the semiarid lands of the tropics, occupy transitional, or intermediate, positions between deserts and the humid climates (Figs. 96 and 97). The general characteristics of these continental steppes have already been analyzed. Because of the greater precipitation than in deserts, the steppes are somewhat better fitted for human settlement, but this, together with the unreliable nature of the rainfall, also makes them regions of greater economic catastrophe (Figs. 92 and 98). A succession of humid years may tempt settlers to push the agricultural frontier toward the desert, but here also drought years are sure to follow, with consequent crop failure and ensuing disaster. Years with below-normal rainfall are more numerous than those in which it is above. Over a considerable part of the American semiarid country, in 30 to 40 per cent of the years, rainfall is less than 85 per cent of the average. During the period 1871–1920, at Ogden, Utah, whose average annual precipitation is 15.2 in., there was one year with rainfall as high as 25 in. and another as low as 6.5.

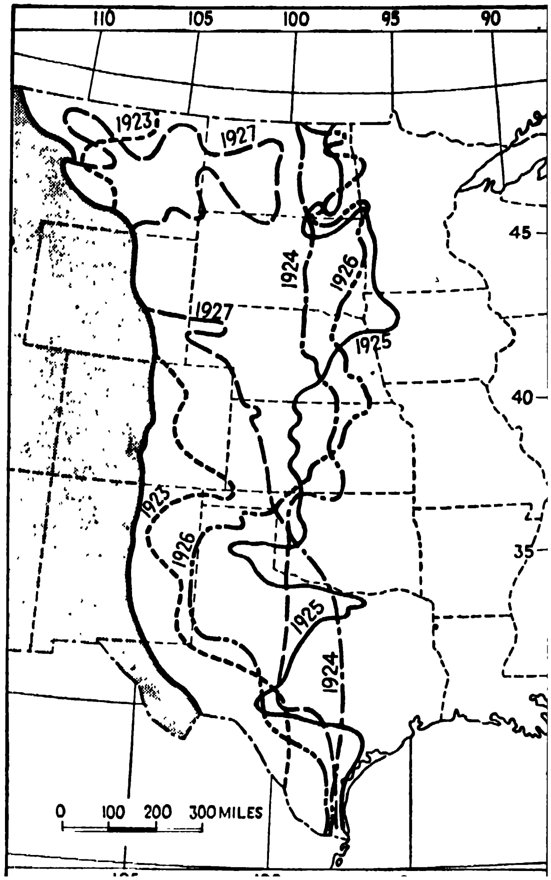

Fig. 98. Fluctuations in the boundary separating dry and humid climates, over a period of 5 years, for the region between the Mississippi River and the Rocky Mountains. (*After H. M. Kendall.*)

A unique feature of the North American steppe lands east of the Rocky Mountains, from Alberta to Colorado, is the frequency and strength of chinook winds. Rapid changes in temperature over short periods of time and large variations in the mean winter temperatures of different years are the result.

234. Resource Potentialities of the Dry Realm. Dry climates are characteristic of

Climatic Data for Representative Stations in Middle-latitude Steppes

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Williston, N.D.								
Temp.	6	8	22	43	53	63	69	67	56	44	27	14	39.2	62.7
Precip.	0.5	0.4	0.9	1.1	2.1	3.2	1.7	1.7	1.0	0.7	0.6	0.5	14.4	
						Quetta, Baluchistan (5,500 Ft.)								
Temp.	40	41	51	60	67	74	78	75	67	56	47	42	58.1	38.2
Precip.	2.1	2.1	1.8	1.1	0.3	0.2	0.5	0.6	0.1	0.1	0.3	0.8	10.0	
						Urga, Mongolia (3,800 Ft.)								
Temp.	−16	−4	13	34	48	58	63	59	48	30	8	−17	28	79
Precip.	0.0	0.1	0.0	0.0	0.3	1.7	2.6	2.1	0.5	0.1	0.1	0.1	7.6	

over one-quarter of the earth's land surface, a proportion larger than for any of the other climatic groups. It is unfortunate that such an unproductive climate should be so extensively distributed. For the most part dry climates are coincident with great gaps or blank spaces on the world-population map. In this respect they are like the thinly populated wet tropics and the cold polar and subarctic lands. These three—the dry, the cold, and the constantly hot climates—offer the greatest obstacles to a large-scale redistribution of population on the earth.

Owing to insufficient rainfall it appears that a large part of the earth's land surface is doomed to remain relatively unproductive, the most arid parts of it even barren wastes. Very recently the success attained in artificially producing precipitation from clouds composed of supercooled water droplets by seeding them with powdered dry ice seems to have revived the hope that man eventually will be able to cause abundant rains to fall in dry climates. This likelihood is exceedingly remote, however, for to begin with, nature must first produce the clouds before man has a chance of stimulating precipitation, and clouds are uncommon features in arid lands. Up to the present time, also, it is only clouds whose top portions, at least, contain supercooled droplets which have been made to yield precipitation artificially, and such clouds are still more rare. What is more, a considerable part of the precipitation falling from clouds in dry climates would be evaporated before reaching the earth's surface.

Further reducing the effectiveness of the meager dry-land precipitation is its great variability from year to year and the pelting nature of the few rains that do fall. Pelting rains are relatively ineffective because such a small proportion enters the ground where it can be used by plants, while a large part disappears in the form of surface runoff thereby causing destructive gullying and slope wash. It would appear as though the expansion of settlement in lands with dry climates will be associated with (*a*) an increased use of irrigation methods and (*b*) the further development and greater use of drought-resistant plants and their cultivation by dry-farming methods. One can scarcely be optimistic, however, about the promise that either of these methods holds for opening up extensive areas of dry land for future agricultural settlement.

The niggardly climate is responsible for a sparse vegetation cover which has relatively low resource value. Some deserts are almost barren wastes, practically devoid of plants having economic value. Other deserts have a thin mantle of widely spaced woody shrubs with some short desert bunch grass. The grazing value of this vegetation is very low. Over the desert area of southwestern United States, more than 75 acres are required to supply natural forage for one steer. In the semiarid regions, or the steppes, short, shallow-rooted, widely spaced grasses prevail. This steppe vegetation has a considerably higher grazing value than has the desert shrub, so that it is capable of supporting more livestock per unit area. Although the humid margins of some middle-latitude steppes have been brought under the plow, it appears that the meager and unreliable rainfall will tend to keep the larger part of the world's steppe lands out of cultivation and in natural grasses. Grass, the greatest natural asset of the steppes, forms the basis for a grazing industry, but grazing is an economy which is able to support only a meager population.

Soils are of little consequence in deserts largely because the deficient rainfall makes it impossible to use them for agricultural purposes. In the steppes the very modest amount of leaching and the humus derived from the root mat of the grasses makes for dark fertile soils of high resource value. Unfortunately this admirable soil resource of semiarid lands cannot be exploited to anything like its capacity because of the precipitation handicap. It is the old story of fruitful soils and prolific climates seldom being areally coincident.

CHAPTER 9: *The Humid Mesothermal*[1] *Climates (C)*

235. Lacking the constant heat of the tropics and the constant cold of the polar caps, middle-latitude climates are characterized by a very definite seasonal rhythm in temperature conditions. Thus temperature becomes coequal with rainfall in determining the various types of middle-latitude climates. In the tropics, seasons are designated as wet and dry; in the middle latitudes they are called winter and summer, and the dormant season for plant growth usually is one of low temperatures rather than of drought. In the intermediate zones the changeableness of the weather is a striking characteristic. This results from the fact that the middle latitudes are the natural region of conflict for contrasting air masses expelled from the tropical and polar source regions. Other than the equatorial region, they are the only great zones of horizontal air convergence. Fronts are therefore numerous, and large numbers of cyclones and anticyclones travel across these intermediate latitudes. The science of weather forecasting is best developed and most useful in the intermediate zones where irregular and nonperiodic weather changes are the rule.

In general, the mesothermal climates lie either on the equatorward margins of the middle latitudes or else in marine locations farther poleward. Both of the subtropical types are intermediate in position and character between the tropical climates on their equatorward sides and the more severe mesothermal and microthermal ones interior and poleward. Only one of the three mesothermal climates, the marine west-coast type, extends into the higher middle latitudes, and this is possible because it characteristically lies along the windward sides of the continents where the westerlies bring oceanic conditions onshore (Fig. 82).

5. Mediterranean or Dry-summer Subtropical Climate (*Cs*)[2]

236. General Features. In its simplest form this climate is characterized by three principal features: (*a*) a concentration of the modest amount of precipitation in the winter season, summers being nearly or completely dry; (*b*) warm to hot summers and unusually mild winters; and (*c*) a high percentage of the possible sunshine for the year and especially in summer. Quite deservedly this climate with its bright, sunny weather, blue skies, few rainy days, and mild winters, and its usual association with abundant flowers and fruit, has acquired a glamorous reputation. It has the unique distinction of being the only one of the earth's humid climates having drought in summer with a strong rainfall maximum in winter. The Mediterranean type is strongly marked in its climatic characteristics, these being duplicated with notable similarity in the five regions where it occurs, *viz.*, the borderlands of the Mediterranean Sea, central and coastal southern California, central Chile, the southern tip of South Africa, and parts of southern Australia.

237. Location. Mediterranean climates characteristically are located on the tropical margins of the middle latitudes (30°–40°) along the western sides of continents. Lying thus on the poleward slopes of the subtropical highs,

[1] Meso-, from Greek *mesos*, middle. Mesothermal, therefore, refers to "middle," or moderate, temperatures.

[2] In the Köppen symbol, *s* = dry season in summer of the respective hemisphere.

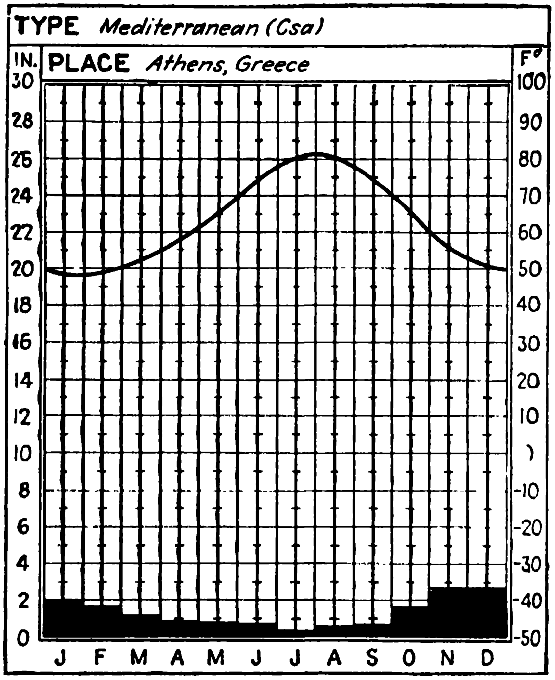

Fig. 99. A Mediterranean station with hot summers.

they are intermediate in location between the dry centers of those anticyclonic cells, on the one hand, and the rain-bringing fronts and cyclones of the westerlies, on the other. With the north-south shifting of wind belts during the course of the year, these Mediterranean latitudes at one season are joined to the dry tropics, and at the other season to the humid middle latitudes. Tropical constancy, therefore, characterizes them in summer, and middle-latitude changeability in winter. Emphatically, this is a transition type between the low-latitude steppes and deserts and the cool, humid, marine west-coast climates farther poleward.

As previously stated, Mediterranean climates are usually confined to the western sides of continents, roughly between latitudes 30 and 40° (Fig. 82, Plate III). In both central Chile and California, mountains terminate the type abruptly on the land side, steppe and desert prevailing interior from the mountains. In South Africa and southwestern Australia the farthest poleward extent of these continents carries them barely to Mediterranean latitudes, so that the dry-summer subtropical climates occupy southern and southwestern extremities rather than distinctly west-coast locations. Only in the region of the Mediterranean Basin, which is an important route of winter cyclones, does this type of climate extend far inland, perhaps for 2,000 miles or more, the extensive development there being responsible for the climate's name. It is the relative warmth of the Mediterranean Sea in winter, and the resulting low-pressure trough coincident with it, that makes the Mediterranean Basin a region of air-mass convergence with a resulting development of fronts and cyclones (Fig. 75). Interiors and eastern margins of continents, with their tendencies toward monsoon systems, are not conducive to the development of Mediterranean climates, more especially their characteristic rainfall regime.

TEMPERATURE

238. Mild Winters. Both because of its latitudinal location and because of its characteristic position on the continents, Mediterranean climate is assured of a temperature regime in which cold weather is largely absent (Fig. 99). Usually the winter months have average temperatures of between 40 and 50°, and the summer months between 70 and 80°, so that mean annual ranges of 20 to 30°+ are common. These are relatively small for the middle latitudes but are larger than those of most tropical climates, except possibly the low-latitude steppes and deserts.

239. Marine Locations (*Csb*).[1] Littoral locations are likely to have somewhat modified Mediterranean conditions. Summers are unusually cool, owing partly to the general marine location, but this condition many times is accentuated by the cool ocean currents offshore (Figs. 100 and 102; see data for Santa Monica, page 168). Thus Mogador, on the Atlantic coast of Morocco, has a hot-month temperature of

[1] In the Köppen symbols *Csb* and *Csa*, the letter *b* indicates cool summers with the temperature of the warmest month under 71.6° (22°C.) but with at least 4 months over 50° (10°C.). The letter *a* indicates hot summers with the temperature of the warmest month over 71.6° (22°C.).

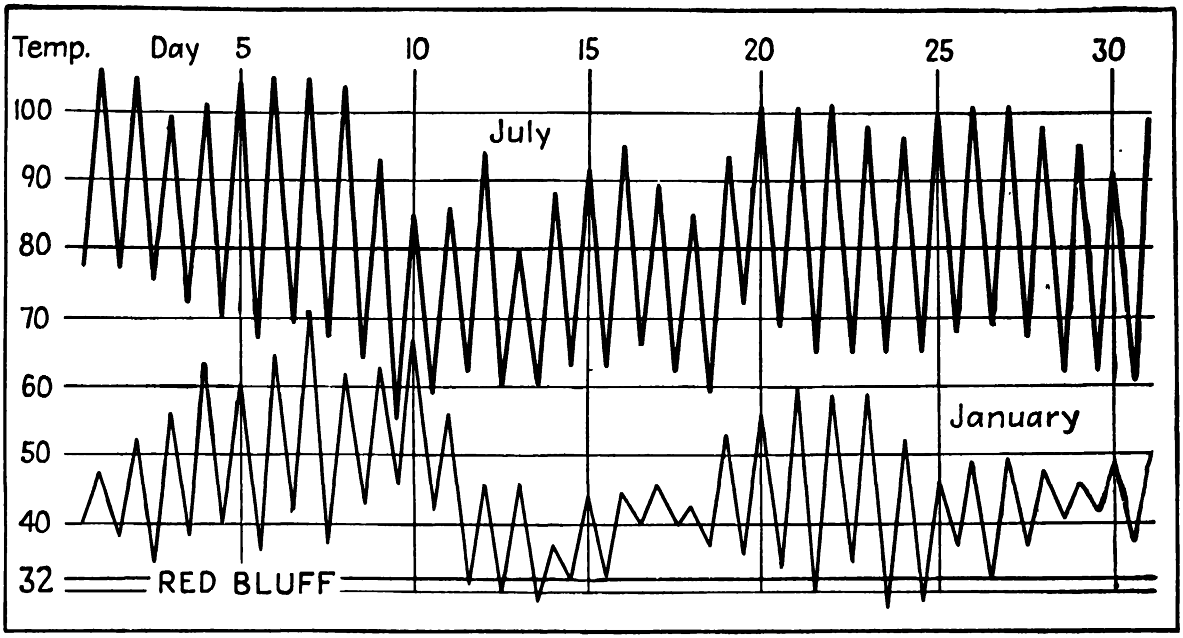

Fig. 104. An interior Mediterranean station in the Great Valley of California.

climates are justly famed. Peoples of the higher latitudes seek them out as winter playgrounds and health resorts. Even interior locations have average cold-month temperatures 10 to 20° above freezing. Thus Sacramento has an average January temperature of 46°, Marseille 43°, and Rome 44°. In southern California, in January, midday temperatures rise to between 55 and 65° and at night drop to 40° ± (Figs. 102, 103, and 104).

The growing season is not quite the whole year, for frosts occasionally do occur during the three winter months. To say that the growing season is 9 ± months does not, however, adequately describe the situation, for while freezing temperatures are by no means unknown during mid-winter months, they occur on only relatively few nights, and rarely are they severe. During a period of 41 years at Los Angeles, there were 28 in which no killing frost occurred; in other words, the growing season was 12 months in length. During a recent January at Red Bluff, Calif., there were 10 nights, and at Sacramento 7, when the temperature dropped below 32°. The lowest temperature ever recorded at Los Angeles is 28°, at Napoli (Naples) 30°, and at Sacramento 17°. Even on the very occasional nights when temperatures do slip a few degrees below freezing, the following day sees them well above 32° again. Never does the thermometer stay below the freezing point for the entire day.

*Temperatures for Selected Mediterranean Cities**

	Av. Annual Minimum	*Absolute Minimum*	*Av. Annual Maximum*	*Absolute Maximum*
Valencia	31	19	99	109
Naples	30	24	94	99
Athens	29	20	100	105

* W. G. Kendrew. "The Climates of the Continents," 3rd. ed. P. 246. Oxford University Press, New York, 1942.

Such frosts as do occur are usually the result of local surface cooling, following an importation of *cP* air, the low temperatures being confined to a shallow layer of surface atmosphere and particularly to depressions in which the cool dense air has collected. For this reason such sensitive crops as citrus are characteristically planted on slopes. Occasionally fires might be lighted among the citrus trees in order to prevent serious damage from freezing. Upon first thought it may seem odd that in Mediterranean climates, where frosts are neither frequent nor severe, un-

usual losses should result from low temperatures. But it is this infrequency and the small degree of frost that make it so treacherous, since the mild winters tempt farmers to grow types of crops, such as out-of-season vegetables and citrus, that are particularly sensitive to cold.

drought-producing controls (subsiding air in the subtropical highs, or onshore winds from over cool ocean currents), and equatorward in winter when the convergent zone of the westerlies with its rain-bringing cyclones prevails. Rainfall therefore is chiefly of frontal origin.

Climatic Data for Representative Mediterranean Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Red Bluff, Calif. (Interior)														
Temp.	45	50	54	59	67	75	82	80	73	64	54	46	62.3	36.3
Precip.	4.6	3.9	3.2	1.7	1.1	0.5	0.0	0.1	0.8	1.3	2.9	4.3	24.3	
Santa Monica, Calif. (Coast)														
Temp.	53	53	55	58	60	63	66	66	65	62	58	55	59.5	13.6
Precip.	3.5	3.0	2.9	0.5	0.5	0.0	0.0	0.0	0.1	0.6	1.4	2.3	14.78	
Perth Australia (Coast)														
Temp.	74	74	71	67	61	57	55	56	58	61	66	71	64	19
Precip.	0.3	0.5	0.7	1.6	4.9	6.9	6.5	5.7	3.3	2.1	0.8	0.6	33.9	

PRECIPITATION

243. Amount and Distribution. Rainfall is generally less than moderate, 15 to 25 in. being a fair average. More characteristic than the amount of rain, however, is its distribution over the year, for there is a pronounced maximum during the cooler months, summer being nearly, if not absolutely, dry (Figs. 99 and 100). If the relatively modest amount of rain typical of Mediterranean climate fell during the hot summers when evaporation is high, semiarid conditions would be the result. But coming as it does in the cooler seasons, much less is evaporated, and more, therefore, is available for vegetation. As a result, Mediterranean climate is more correctly described as subhumid than as semiarid. The name *dry-summer subtropical* is useful, therefore, in distinguishing this climate from its wetter counterpart, the *humid subtropical* climate located on the eastern sides of continents in similar latitudes.

Over three-quarters of the precipitation in Los Angeles falls during the period December to March, and 2 per cent during June to September. The rainfall regime, therefore, is alternately that of the deserts in summer and of the cyclonic westerlies in winter when rain is relatively abundant. This seasonal alternation of drought and rain results from a latitudinal shifting of air-mass control and rain belts following the sun, poleward in summer, bringing Mediterranean latitudes under the influence of

Lying as they do between steppe and desert on their equatorward sides and the rainy marine west-coast climate farther poleward, Mediterranean climates show a gradual increase in rainfall from their equatorward to their poleward margins. This is well illustrated by three California cities, arranged in order from south to north. San Diego, farthest south, has only 10 in. of rain, Los Angeles 15 in., and San Francisco 20 in. Precipitation also tends to increase from the interiors toward the coasts, except where elevations may modify the rule. A snow cover is absent at low elevations, and even snowfall is rare. Over Mediterranean central and southern California (excluding the mountains) annual snowfall averages less than 1 in., and there is none at all along the coast from San Luis Obispo southward. In all Mediterranean regions snow is so rare that it is a matter for comment when it does fall. Where highlands are present in Mediterranean regions, as they commonly are, they may have a moderate to heavy snow cover. This snowfall in Mediterranean highlands provides an invaluable source of irrigation for the adjacent drier lowlands.

244. Winter Rainfall and Cloudiness. But although winter is the rainy season, it is by no means dismal and gloomy as are the west-coast regions farther poleward at that season. Since Mediterranean latitudes usually are on the equatorward sides of the storm centers, and far removed from most of them, they experience a

less persistent cloud cover, and sunshine is abundant even in winter. To be sure, winters are considerably cloudier than summers, but still there is much bright sunny weather. In interior Mediterranean California, midsummer months have over 90 per cent of the possible sunshine, but in winter this is reduced to 50 per cent or less, although farther south in the vicinity of Los Angeles it reaches 60 to 70+ per cent. Dull gray days with persistent long-continued rain are by no means rare, but showery conditions with a broken sky are more common. After the rain the sun seems to shine more brilliantly than ever in the washed and dust-free atmosphere.

245. Summer Drought and Sunshine. Summers in the dry-summer subtropics are periods of brilliant sunshine, extremely meager precipitation, nearly cloudless skies, and desert-like relative humidity. Thus Sacramento has no rain at all in July and August, and in those months the percentage of the possible sunshine received is 95 and 96, respectively. Afternoon relative humidity is in the neighborhood of only 30 to 40 per cent. Los Angeles has, on the average, only one rainy day during the three summer months; San Bernardino has two; and Red Bluff, three. The low rainfall, dry heat, abundant sunshine, and excessive evaporation characteristic of interior Mediterranean summers, are ideal for out-of-doors drying of fruits on a large scale. In spite of the summer heat, thunderstorms are rare, except possibly in the mountains or hills, two to four a year being the usual number in southern California. The dry settling air of these regions in summer or the onshore winds from over cool ocean currents are scarcely conducive to the formation of cumulo-nimbus clouds.

Coastal regions, especially if paralleled by cool ocean currents, are characterized by high relative humidity and much fog. Rarely does it remain foggy for the entire day, the mists usually being burned off by the ascending sun after 9:00 or 10:00 A.M. Nights, however, may be damp and unpleasant. The coast of California is one of the foggiest areas in the United States, parts of the littoral having 40+ days with dense fog per year. These coastal sections with their cool, humid, and less sunny summers are really a subtype of general Mediterranean climate.

246. Dependability of Precipitation. Like most subhumid climates, this one suffers from a rainfall that is none too reliable, although it fluctuates less than a summer-maximum regime having the same amount. At San Bernardino, Calif., where the annual rainfall averages 16.1 in., during a 48-year period it has been as low as 5.5 and as high as 37.1. In 5 of the 48 years it has been below 10 in. The somewhat precarious, as well as subhumid, character of the precipitation compels a relatively great dependence upon irrigation.

SEASONAL WEATHER

247. Summer. Daily weather is less fickle in the subtropical climates than it is farther poleward, where moving cyclones and anticyclones are more numerous and better developed. A typical *summer* day in the Mediterranean type is almost a replica of one in a low-latitude desert. Moreover, one day is much like another. Drought, brilliant sunshine, low relative humidity, high daytime temperatures, and marked nocturnal cooling are repeated day after day with only minor variations. Along seacoasts, and for a short distance inland, the daily sea breeze is often a marked phenomenon, greatly meliorating the desert heat. Regions with Mediterranean climates are famous for their well-developed sea breezes, the cool water offshore and the excessive heating of the dry land under intense insolation providing ideal conditions for strong daytime indrafts of air.

In *autumn* winds become less regular and uniform. As the cyclonic belt creeps equatorward, following the sun's rays, an occasional low with its associated cloud cover and rain makes itself felt. The dry and dusty land begins to assume new life under the influence of increasing precipitation. Temperatures are still relatively high. As sun control loses something of its summer dominance, daily weather becomes more uncertain, and "spells of weather" become more frequent.

Winter witnesses an increase in the frequency and strength of cyclones, and it is in that season

that irregular, nonperiodic weather changes are most marked. Rainy days, brought by lows the centers of which are often well poleward from Mediterranean latitudes, are sandwiched in between delightfully sunny ones, in which the days are comfortably mild, even though the nights may be chilly with occasional frosts.

Spring is a delightful season of the Mediterranean year: fresh and yet warm. On the whole it is cooler than autumn. This is the harvesting period for many grains. Passing cyclones gradually become fewer as summer approaches, but nonperiodic weather changes are still significant.

248. Resource Potentialities of the Mediterranean Realm. This, the most restricted of all the principal climatic types, embracing less than 2 per cent of the earth's land surface, is, nevertheless, one of the most unique and glamorous. Its abundance of sunshine, fruit, and flowers; its mild and relatively bright winter weather offering resort and outdoor sport attractions; its blue skies and even bluer waters create for it a reputation and renown far out of proportion to its small area. Perhaps, also, the fact that the ancient civilizations, from which stem some of the most monumental elements of our present culture—literature, religion, science, art—developed within the Mediterranean Basin and bear an indelible imprint of that environment may have had no small part in establishing the fame of the Mediterranean climate.

In the Mediterranean climate is found a unique combination of elements, some of which make for high agricultural productive capacity, and others which have the opposite effect. It is more particularly in the temperature elements—long, warm-to-hot summers with abundant sunshine; mild, bright winters; and almost a year-round frost-free season—that this climate exhibits its highest potentialities. For any part of the middle latitudes the two subtropical realms represent the nearest approach to the bountiful temperature regime of the tropics. This close approach to tropical temperature conditions, while still lying within the middle latitudes and profiting by proximity to their markets, gives to these two realms a considerable part of their distinctive character. In them is permitted the development of certain heat-loving or frost-sensitive crops, some of them of a luxury type—citrus, figs, viniferous grapes, rice, sugar cane, cotton—which can be grown in few other parts of the middle latitudes. The subtropical climates likewise permit the development of out-of-season vegetables and flowers for the markets of regions farther poleward, where a season of severe cold imposes a long dormant period. The possibility, within the Mediterranean realm, of utilizing the middle-latitude winter as an active growing and producing season offers unusual possibilities. In addition, the mild and moderately bright winters make the Mediterranean realm attractive as a winter playground for peoples from the higher middle latitudes. Here snow and ice and frigid temperatures are left behind, and out-of-doors living can be enjoyed even in midwinter. The proximity of the sea is a further attraction. There is no doubt that climate, especially winter climate, is one of the Mediterranean realm's greatest natural assests.

On the other hand, it is (*a*) the relatively meager total precipitation as well as (*b*) the long summer drought which place definite climatic limitations upon production within the realm. It is this deficiency of water, especially in the warm season, which makes of summer, in spite of its abundant heat, a naturally dormant season. The large-scale development of irrigation within the Mediterranean realm is evidence of man's attempt to overcome the handicap of summer drought and thereby provide a year-round growth for crops. Except where irrigation is practiced the relatively meager total precipitation and the arid summers tend to place limitations upon the kinds of crops grown, emphasizing drought-resistant perennials such as the olive and vine or those annuals which mature quickly such as barley and wheat. Fortunately, the usual 15 to 25 in. of rain is concentrated in the cooler seasons of the year when evaporation is at a minimum. If the same amount fell during the hot summer when evaporation is excessive, much less of it would be effective for plant growth.

The modest precipitation coupled with the

summer drought produce a vegetation cover characterized by woody shrubs and widely spaced stunted trees. In some Mediterranean regions scattered patches of desert bunch grass are also present. This plant cover is of modest value for grazing, particularly of sheep and goats. Only on the higher hill lands and the mountain slopes are the forests of genuine commercial value, the stunted trees and the bushes of the valleys and the lower slopes being useful chiefly as checks to erosion.

Because of the widespread occurrence of hill land in this realm, mature residual soils are not common. On the slopes soils are inclined to be thin and stony, and to a considerable extent they remain uncultivated. It is the young alluvial soils of the valleys which are the attractive sites for cultivation.

6. Humid Subtropical Climate (*Ca*)[1]

249. Three principal differences distinguish the humid subtropical from the dry-summer subtropical climates: (*a*) the former is characteristically located on the eastern rather than on the western sides of continents; (*b*) it has a more abundant precipitation; and (*c*) this precipitation is either well distributed throughout the year or else concentrated in the warm season. Even where the warm-season maximum is not emphatic, summer is still humid and usually has adequate rainfall for crops.

250. Location. In latitudinal position the two subtropical climates are similar, both of them being on the equatorward margins of the intermediate zones but with the wet phase extending somewhat farther equatorward. Characteristically it extends from latitude 25° ±, poleward to 35 or 40° (Fig. 82, Plate III).

Since they are in similar latitudes, one might reasonably expect these two subtropical climates to experience a similar rainfall regime. It is chiefly the tendency toward a monsoon system of winds on the more continental leeward sides of middle-latitude land masses that interferes there with a normal latitudinal shifting of wind and storm belts, such as takes place along subtropical western littorals. The western, or windward, side of a continent in middle latitudes is too marine in character to create a genuine monsoon. Where land masses are large, and consequently seasonal differences in temperature comparatively great, as in Asia and North America, monsoon tendencies are relatively well developed. The stronger the monsoon tendency, the greater the concentration of precipitation in the warm season.

Since warm ocean currents parallel the subtropical *eastern* coasts, while cool waters are more common along *western* littorals in similar latitudes, there is additional reason for the former having more abundant rainfall, especially in summer.

Lying as they do on the equatorward margins of the middle latitudes, and just beyond the poleward margins of the tropics, the humid subtropical, like the dry-summer subtropical, climate is a transitional type. But here the similarity in location ends, for while Mediterranean climate is characteristically bordered by low-latitude steppe and desert on its equatorward side, humid subtropical climate is terminated by humid tropical types, *viz.*, savanna and tropical rainforest. This contrast has a marked effect upon the kinds of importations from the low latitudes in the two types, parching dry heat accompanied by dust in the one case, and humid sultry heat in the other. On their poleward sides they likewise make contact with contrasting types, for while Mediterranean generally merges into the mild rainy marine west-coast climate, humid subtropical not infrequently makes contact with severe continental climate. This is particularly true of North America and Asia, where there are extensive land masses in the higher middle latitudes. On their landward or western margins humid subtropical climates gradually merge into dry types characteristic of the continental interiors (Fig. 82).

TEMPERATURE

251. Temperatures like Those of the Mediterranean Type. In temperature characteris-

[1] In the Köppen symbols, f = humid throughout the year; w = dry season in winter of the respective hemisphere; and a = temperature of warmest month over 71.6° (22°C.).

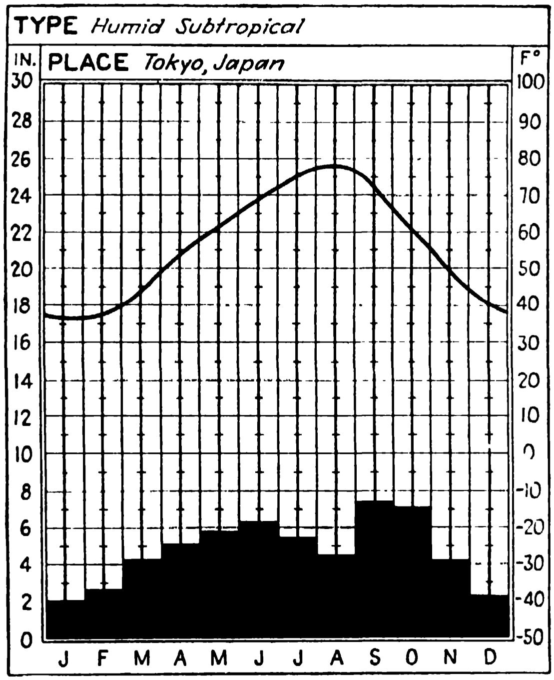

Fig. 105

tics the humid subtropics are similar to Mediterranean climate, but there is somewhat less contrast between coastal and interior locations (Fig. 105). This similarity is not unexpected since the two types roughly correspond in their latitudinal locations. Because warm, instead of cool, ocean currents wash the subtropical eastern coasts of continents, there can be no distinctly cool littorals such as are characteristic of some Mediterranean coasts. Cool, foggy stations, like San Francisco or Mogador, are absent.

252. Summer. Average hot-month temperatures of 75 to 80° are characteristic. Along the immediate coasts, especially of the smaller Southern Hemisphere land masses, they are as often below as above 75°. But everywhere summers are distinctly warm to hot, and this is particularly true of North America and Asia. Thus hot-month temperatures average 81° at Charleston, S.C.; 80° at Shanghai, China; 77° at Brisbane, Australia; 77° at Durban, South Africa; and 74° at Buenos Aires, Argentina.

Not only the air temperature, but also the absolute and relative humidity are high. The high humidity in conjunction with the high temperatures produces a sultry, oppressive condition with low cooling power. Sensible temperatures, therefore, are commonly higher in the humid- than the dry-summer subtropics, even when the thermometer registers the same. Summer heat in the American Gulf States, where *mT* Gulf air prevails, closely resembles that of the tropical rainforest climate. At New Orleans during June, July, and August the average temperatures are 2 to 3° higher than they are at Belém in the Amazon Valley, while the amount of rainfall is nearly the same. In the humid subtropics of Japan and China Europeans and Americans frequently quit their usual places of residence during summer and go to high-altitude stations as they do in the genuine tropics. The average of the daily maxima in July throughout most of the American Cotton Belt is between 90 and 100°, while the highest temperatures ever observed are usually between 100 and 110° (Figs. 106, 107, and 108).

253. *Night Temperatures.* Not only are the days hot and sultry, but the nights are oppressive as well, the humid atmosphere with more cloud preventing the same rapid loss of heat that takes place in the drier air and clearer skies of Mediterranean climates. The sultry nights are an additional item of resemblance to the wet tropics. The slower night cooling results in relatively small diurnal ranges, usually only one-half to two-thirds as great as those in the dry-summer subtropics (compare Fig. 104 with Figs. 106 and 107). Since the sun is very much in control of the daily weather, one day in summer is much like another in the humid subtropics.

254. Winter. Winters are, of course, relatively mild in subtropical latitudes, cool-month temperatures usually averaging between 40 and 55°. Thus Montgomery, Ala., has an average cool-month temperature of 49°; Shanghai, China, 38°; Buenos Aires, Argentina, 50°; and Sydney, Australia, 52°. Annual ranges are usually small, although there is considerable variation, depending upon the size of the continent and the latitudinal location of the station. At Buenos Aires the annual range is only 23°, at Sydney 19°, but at Montgomery it is 32°, and it is 43°

at Shanghai. Apparently the larger the land mass and the better the development of monsoon winds, the colder are the winters and the larger the annual ranges. In eastern Asia the strong monsoonal outpouring of cold polar continental air in winter from the large land mass to the rear results in the lowest *average* winter temperatures in those latitudes for any part of the world.

The midday temperatures in winter are likely to be pleasantly warm, the thermometer usually rising to 55 or 60°. On winter nights temperatures of 35 to 45° are to be expected. These certainly are not low, but combined with a

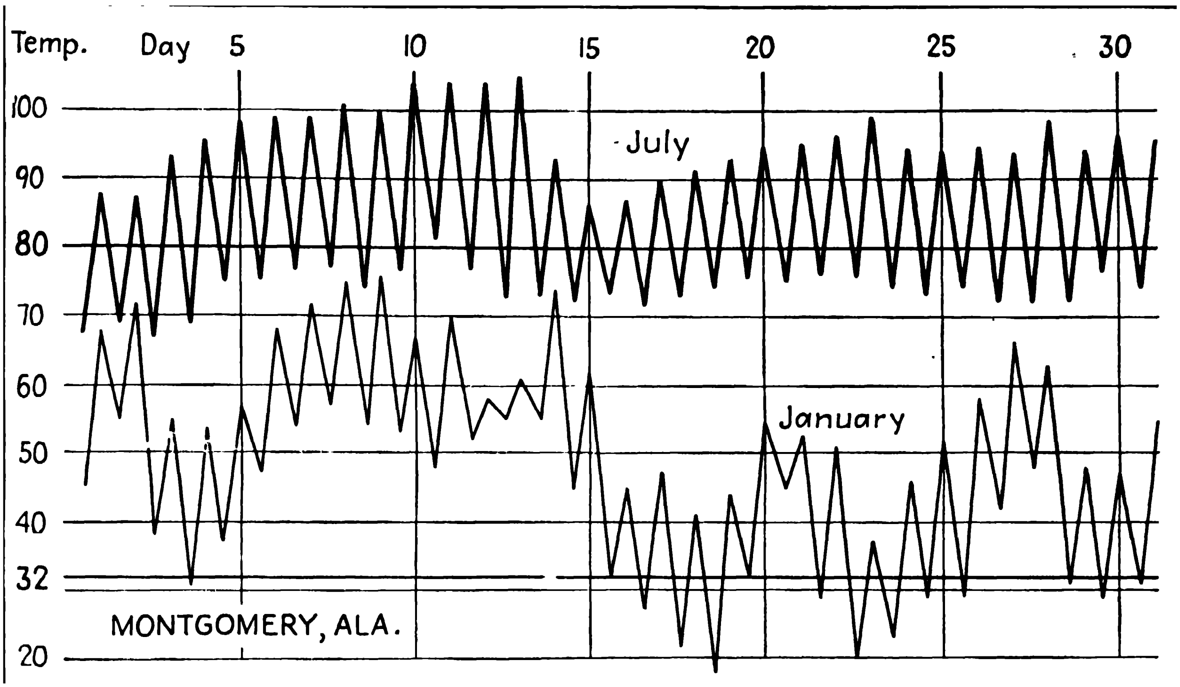

Fig. 106. A humid subtropical station in the American Cotton Belt.

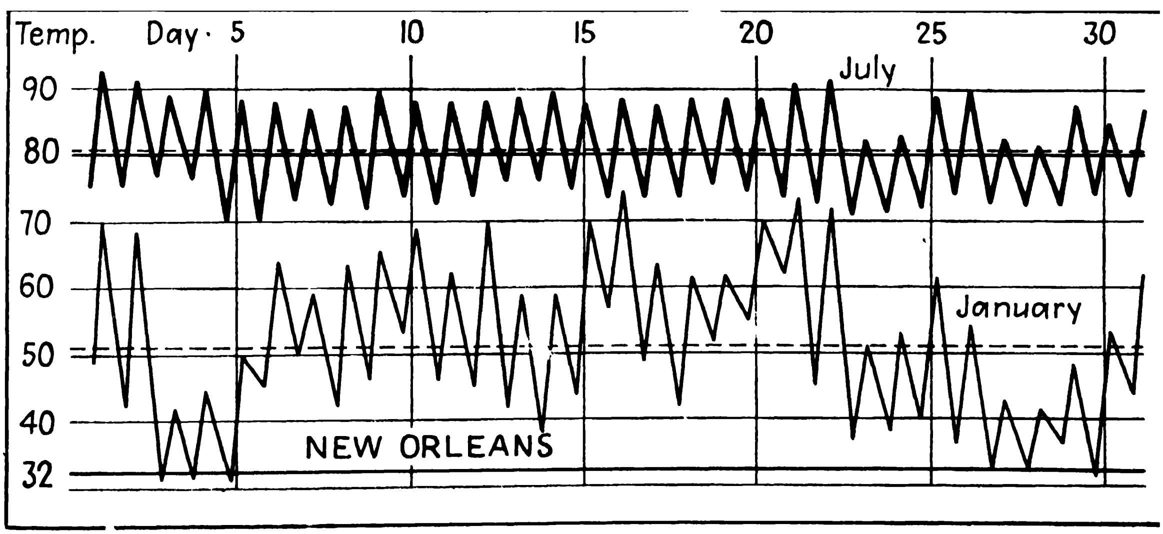

Fig. 107. A humid subtropical station on the Gulf of Mexico.

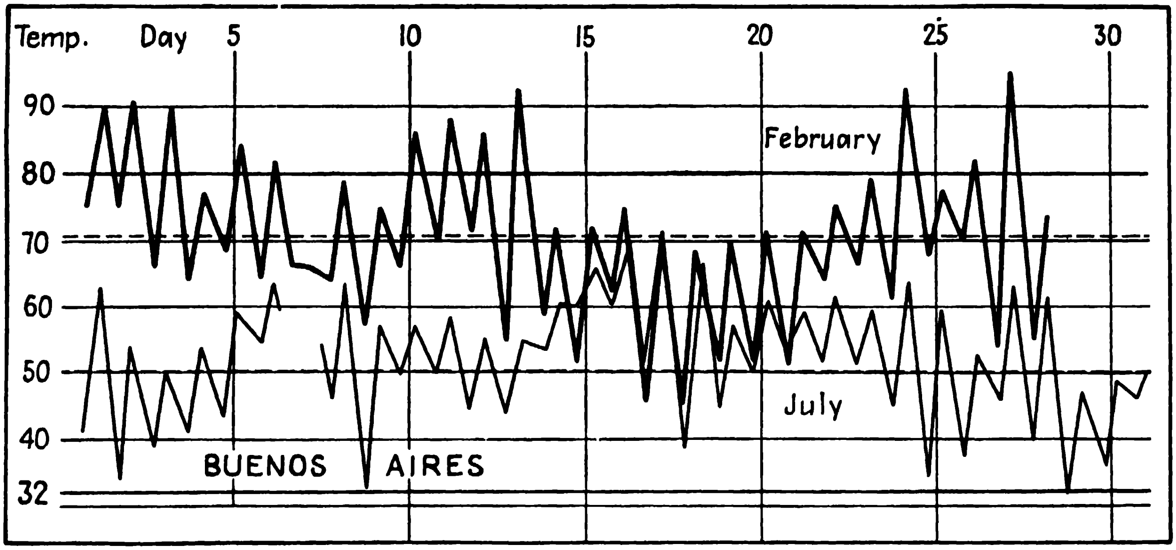

Fig. 108. A humid subtropical station in Argentina.

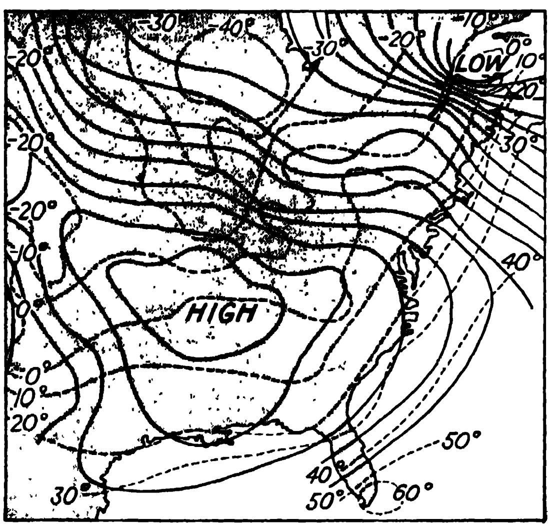

Fig. 109. Weather controls giving rise to killing frosts in the American humid subtropics. A well-developed anticyclone advancing from the northwest as a mass of polar continental air produced minimum temperatures of 20° at New Orleans and 8° at Memphis. The isotherm of 20° fairly well parallels the Gulf and South Atlantic Coasts. (*U.S. Daily Weather Map, Feb. 9, 1933, 8* A.M. *E.S.T.*)

characteristically high humidity they are likely to produce a sensible temperature which is distinctly chilly and uncomfortable. Summer is so much the dominant season that little thought is given to the heating systems in homes, and as a result they are likely to be inefficient and ineffective. Consequently one is often more uncomfortable indoors than he is in colder regions farther poleward where adequate provision is made for winter heating.

255. *Minimum Temperatures and Frost.* It is to be expected that the growing season, or period between killing frosts, will be long. It is usually at least 7 months and from that up to nearly, if not quite, the entire year. Even though freezing temperatures may be *expected* during a period of several months, they actually occur on only a relatively few nights of the winter season. As in the Mediterranean climates, so too in these, the long growing season and infrequent severe frosts make them ideal regions for sensitive crops and for those requiring a long maturing period. In sections of the Southern Hemisphere humid subtropics frost does not occur every winter and usually is light when it does come. Thus the *average* lowest winter temperature at Brisbane, Australia, is 37°, and at Sydney 39°. The lowest temperature *ever recorded* at Buenos Aires is 28°; at Montevideo, Uruguay, 25°; and at Brisbane, Australia, 36°.

One of the distinguishing features of the South Atlantic and Gulf States of the United States, a region where the *average winter temperatures* are relatively high, is the unusually *low winter minima*, even lower than those of China. Thus while southeastern China has lower *average* winter temperatures, the American humid sub-

tropics have severer *cold spells* and consequently lower minima. Several killing frosts are of annual occurrence, and temperatures as low as 10° have been recorded along the ocean margins of all the Gulf States (Fig. 109). No other part of the world near sea level in these latitudes experiences such low winter minima. This is due to the open nature of the North American continent east of the Rocky Mountains which permits the surges of cold polar continental air to move rapidly southward into subtropical latitudes. In the Mediterranean region of California, mountain barriers prevent such severe invasions of cold air, so that there the absolute minima are much higher. Thus while commercial citrus production extends north to about 38° in California, it is confined to regions south of latitude 30 or 31° in southeastern United States. In China the more hilly and mountainous surface configuration prevents such unrestricted latitudinal importations of cold air.

Climatic Data for Representative Humid Subtropical Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Charleston, S.C.														
Temp.	50	52	58	65	73	79	82	81	77	68	58	51	66.1	31.4
Precip.	3.0	3.1	3.3	2.4	3.3	5.1	6.2	6.5	5.2	3.7	2.5	3.2	47.3	
Shanghai, China														
Temp.	38	39	46	56	66	73	80	80	73	63	52	42	49	42.8
Precip.	2.8	2.0	3.9	4.4	3.3	6.6	7.4	4.7	3.9	3.7	1.7	1.3	45.8	
Sydney, Australia														
Temp.	72	71	69	65	59	54	52	55	59	62	67	70	63	20
Precip.	3.6	4.4	4.9	5.4	5.1	4.8	5.0	0	2.9	2.9	2.8	2.8	47.7	

PRECIPITATION

256. Amount and Distribution. Rainfall is relatively abundant (30 to 65 in.) within the humid subtropics, but still there are considerable differences within the several regions. On the landward frontiers of this type, where it makes contact with steppe climates, rainfall reaches the lowest totals. In general there is no marked drought season as there is in the dry-summer subtropics, although summer usually has more precipitation than winter. In the Southern Hemisphere where the monsoon tendency is weak, the seasonal accent is less marked. China, on the other hand, having the best developed monsoons with the fewest cyclonic interruptions in winter, has the greatest rainfall contrasts between summer and winter.[1] Probably because of the strong cyclonic control in late winter and early spring, portions of the American humid subtropics inland from the Gulf and Atlantic (Tennessee and parts of adjoining states) have more rain in the winter half year than in the summer half.

257. Warm-season Rainfall. A considerable part of the summer rainfall at low elevations originates in convectional storms, many of them accompanied by thunder and lightning. In fact the American humid subtropics are the most thundery part of the United States, a large portion of that area having over 60 electrical storms a year, while a small part of Florida has over 90. These storms are mostly of local origin, resulting from strong surface heating of the potentially unstable *mT* Gulf air masses. The normal high temperatures and high humidity of the *mT* air provide an ideal environment for vigorous development of local convection.

In addition to the thunderstorm rain, falling from cumulus clouds, a considerable part is also obtained from weak cyclonic storms and, in the late summer and early fall, from tropical hurricanes as well. In the weak shallow lows rain often falls steadily from gray overcast skies and is general over larger areas than is true of thunderstorm precipitation. Hurricane rainfall is largely confined to the American and Asiatic humid subtropics, giving parts of both those regions late-summer maxima in their precipitation curves. Not only are the heavy late-summer and early-autumn hurricane rains occasionally disastrous to ripening crops and

[1] Parts of the Chinese humid subtropics have genuinely dry winters. These are Köppen's *Cw* areas.

the cause of serious floods, but the accompanying violent winds may play havoc with coastwise shipping and port cities.

In spite of the abundant summer rainfall characteristic of the humid subtropics, sunshine is relatively abundant, although much less so than is true of summers in Mediterranean climates. Montgomery, Ala., receives 73 per cent of the possible sunshine in June and 62 per cent in July.

258. Cool-season Rainfall. In winter the ground is cooler than the poleward moving tropical air masses so that the latter are chilled at the base and made more stable. As a consequence local convection is unlikely. Only as the tropical maritime air masses are forced to rise over relief barriers or over masses of cold air does precipitation usually occur. Winter rainfall over lowlands is chiefly frontal or cyclonic in origin. It is, therefore, usually associated with a general and persistent cloud cover extending over wide areas, from which precipitation may fall steadily during a large part of the day or even more. On the whole it is less violent, but of longer duration, than are the summer thundershowers. Because of the more numerous cyclones, winters are cloudier than summers. At Shanghai, China, in an average January, only 2 in. of rain falls, but there are 12 rainy days, whereas the 6 in. of August precipitation falls on only 11 days. Each rainy day in August, therefore, accounts for three times as much precipitation as a rainy day in January. Montgomery, Ala., which has 73 per cent of the possible sunshine in June, receives only 49 per cent in January and 44 per cent in December. Gray overcast days with rain are unpleasantly chilly. Snow falls occasionally when a vigorous winter cyclone swings well equatorward, but it rarely stays on the ground for more than a day or two. On the northern margins of the American Gulf States snow falls on 5 to 15 days a year, and the ground may be covered for an equally long period.

SEASONAL WEATHER

259. Irregular nonperiodic weather changes are usually less marked in the humid subtropics than they are farther poleward, where the conflict between air masses is more marked and fronts more numerous. In *summer* when the frontal belt or storm belt is farthest poleward, and the sun is largely in control, irregular weather changes are at a minimum (Figs. 106 and 107). Weak cyclones may bring some gray days with general widespread rains. Humid, sultry days with frequent thundershowers, each day much like the others, are the rule. The thermometer rises to about the same height each day and sinks to similar minima each night. *Late summer and fall* are the dreaded hurricane season, and, although these storms are not numerous, their severity more than makes up for their infrequency. Sunny autumn days furnish delightful weather, although the equatorward advancing cyclonic belt gradually produces more gray cloudy days and unseasonable temperature importations as winter closes in. In *winter* the belt of fronts is farthest equatorward, so that irregular weather changes are most frequent and extreme at that time. The arrival of tropical air masses may push the day temperatures to well above 60 or even 70°, whereas the subsequent northwest winds of polar origin may reduce the temperature as much as 30° within 24 hr., resulting occasionally in severe freezes. Bright, sunny winter days are distinctly pleasant and exhilarating out of doors. *Spring* again sees the retreat of the cyclonic belt and the gradual reestablishment of regular diurnal sun control.

260. Resource Potentialities of the Humid Subtropics. Without doubt this is the most productive climate of the middle latitudes. Temperature and rainfall here combine to produce the closest approach to humid tropical conditions outside the low latitudes. Those temperature assets stressed for the Mediterranean realm, in an earlier section, are closely duplicated in this second of the subtropical climates. But if the two subtropical climates are similar in their temperature potentialities, they are in greater contrast as regards rainfall. It is the more abundant precipitation of the humid subtropics, in conjunction with the lack of a genuinely dry season, which makes this realm potentially more productive climatically than its subhumid

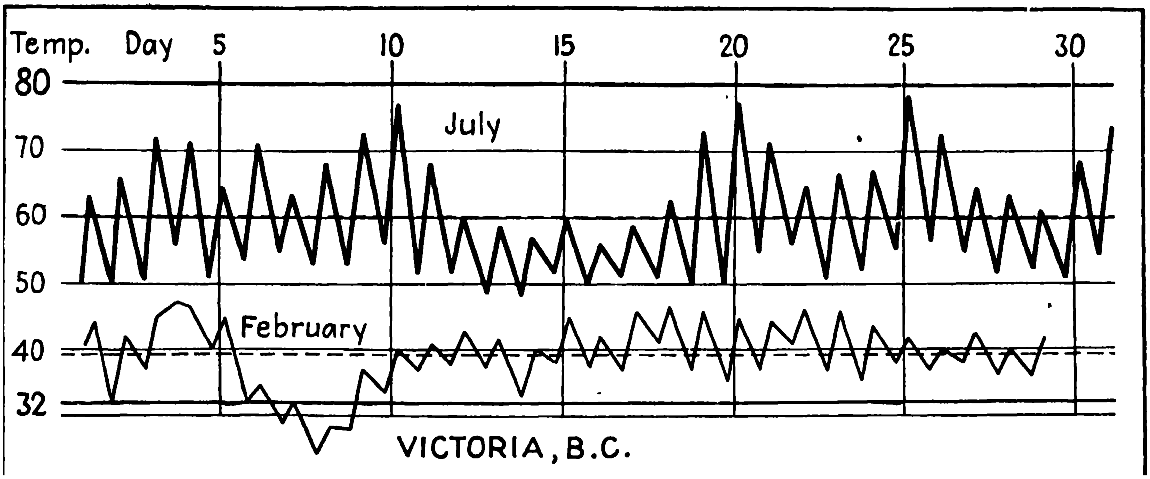

Fig. 112. A marine west-coast station in western Canada.

prolonged hot waves, however, are very few (see temperature data, page 181).

263. Winter. Winters, on the whole, are more abnormally mild for the latitude than the summers are cool. This is particularly the case with western Europe, where a great mass of warm water, the North Atlantic Drift, lies offshore. Thus the most marine parts of western Europe are 20 to 30° too warm for their latitudes in January. In winter isotherms tend to parallel these coasts rather than follow the lines of latitude, indicating the dominance of land-and-water control. The decrease in temperature is much more rapid from the coast toward the interior than it is going poleward. Thus Paris is 7° colder in January than Brest, which is 310 miles nearer the ocean. January averages of 35 to 50° in western Europe are matched by others of 0 to −40° in the continental climates of interior Asia in similar latitudes.

264. *Winter Minima and Frosts.* The average cold-month temperature at London is 39°; at Seattle, 40°; at Valentia, Ireland, 45°; and at Valdivia, Chile, 46°. Annual ranges are small: 15° at Valentia, 23° at London, 13° at Valdivia, and 24° at Seattle. For Seattle the average of the January daily minima is 35°, so that on a majority of nights frost is absent. At Paris frost occurs on about one-half of the nights in the three winter months, whereas in London the thermometer remains above the freezing point on more January nights than it goes below. At Seattle the thermometer has fallen as low as 3°, and at London to 9°. The prevailingly cloudy skies and humid atmosphere in winter tend to retard nocturnal cooling, thereby reducing the diurnal range of temperature (Figs. 112, 113, and 114).

Frosts are more frequent, as well as more severe, and the frost-free season is shorter than in Mediterranean climates. Nevertheless the growing season is unusually long for the latitude, 180 to 210 days being characteristic of the American North Pacific Coast region. Seattle has only 4 months when temperatures below freezing are to be expected. However, winter is usually severe enough to produce a dormant season for plant life, which is not true for the dry-summer subtropics farther equatorward. During unusually cold spells temperatures may remain constantly below freezing for a period of several days. Midday temperatures of normal winter days are relatively high, however, the average of the daily maxima for January at Seattle being 44°, and the daily range less than 10°. On the whole, the day-to-day temperature changes are much less regular in winter than in summer, the former season being more completely controlled by the succession of cyclones and anticyclones.

265. *Cold Spells.* Unusual cold spells in these marine climates characteristically are caused

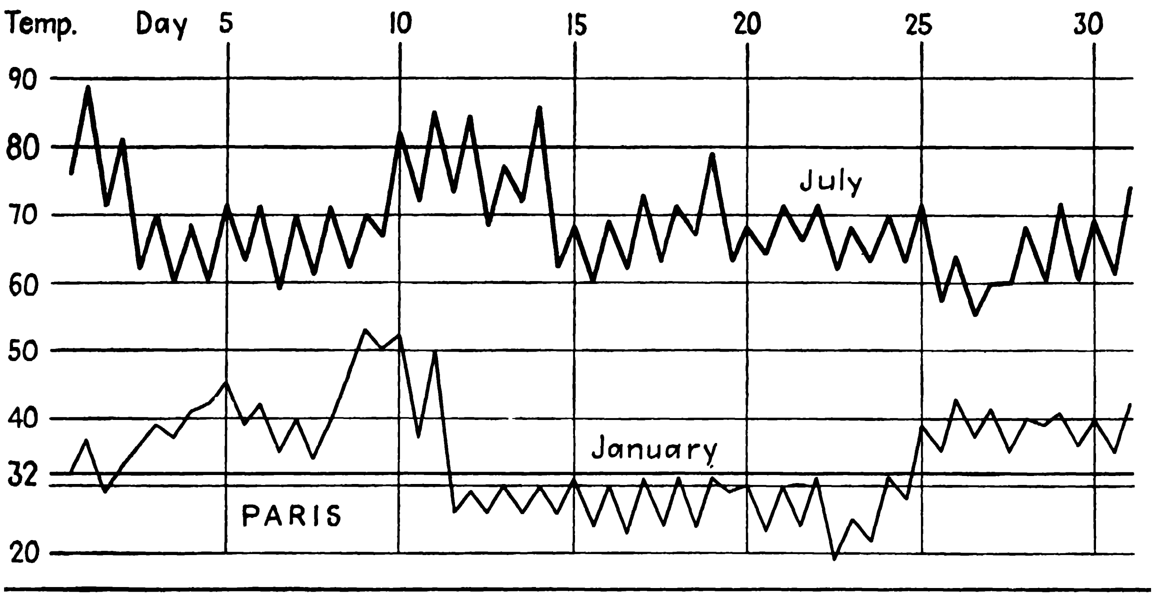

Fig. 113. A marine west-coast station in western Europe.

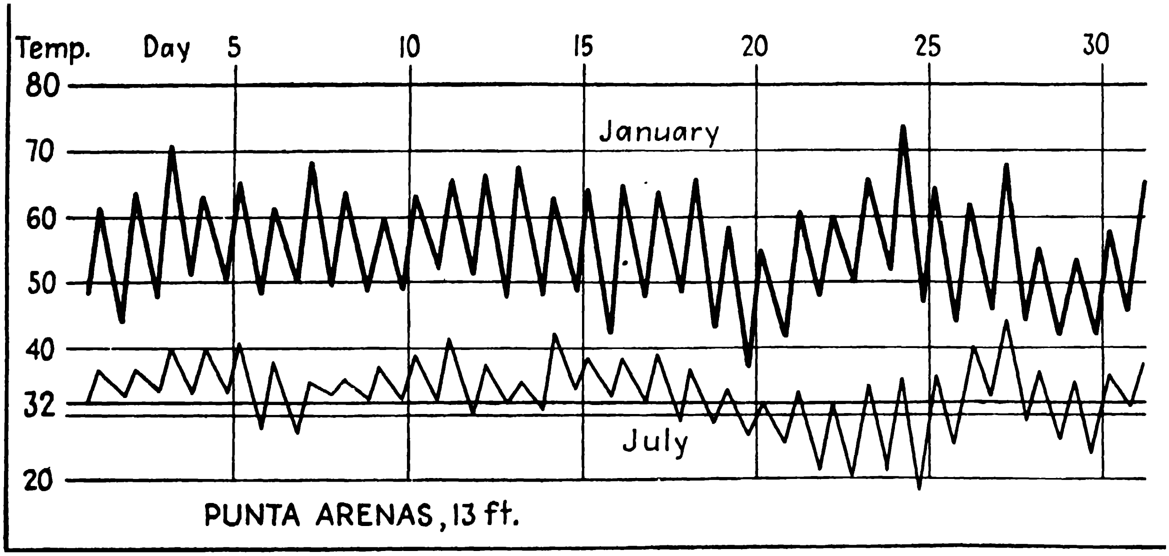

Fig. 114. Daily maximum and minimum temperatures for the extreme months at a cool marine station in extreme southern Chile. The average temperature of the warmest month at Magallanes (Punta Arenas) is about 50°, but since its average annual temperature is above 32° it is scarcely genuine tundra.

by importations of cold polar continental air from the anticyclonic interiors. But such invasions of polar continental air are infrequent for they are opposed to the general westerly air movement of the middle latitudes. The American North Pacific Coast is further protected against invasions of cold continental air by mountain barriers. Northeasterly, and not northwesterly, winds bring the coldest weather to the American North Pacific Coast and to western Europe (Fig. 115). During an unusual February cold spell in Europe, illustrated by Fig. 115, the influence of the continental high persisted for several weeks. During that spell

temperatures in eastern Kent, England, remained continuously below freezing for 226 hr., the Thames was frozen over in many parts, and practically the whole of the British Isles was frost-bound for 5 weeks (Kendrew). On the continent at this same time German coastal cities recorded temperatures below zero, while the Rhine was frozen throughout almost its entire course.

PRECIPITATION

266. Amount. These are humid climates with adequate rainfall at all seasons (Fig. 110). The total amount, however, varies greatly from region to region, depending in a large measure upon the character of the relief. Where lowlands predominate, as they do in parts of western Europe, rainfall is only moderate, usually 20 to 35 in. But, on the other hand, where west coasts are elevated and bordered by mountain ranges, as is the case in Norway, Chile, and western North America, precipitation may be excessive, even reaching such totals as 100 to 150 in. Compensating for this contrast in amount is a further contrast in regional distribution, for where lowlands exist, moderate rainfall prevails well into the interior of the continent; but where coastal mountains intercept the rain-bearing winds, precipitation is confined pretty much to the littoral. East of the mountains drought conditions may prevail. There is no doubt that an *extensive* distribution of *moderate* rains is economically more desirable than the concentration of large and unusable quantities on a mountainous coast. Unfortunately, Europe is the only one of the three

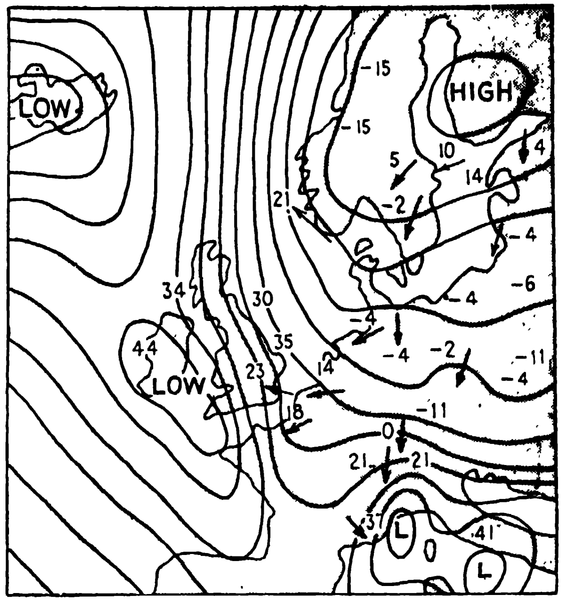

Fig. 115. Weather controls favoring severe cold in western Europe; a high to the north and east is delivering *cP* air to the regions south and west. (*After Kendrew.*)

continents extending well into the westerlies where the windward side of the land mass is freely open to the entrance of the rain-bearing winds. The precipitation of these marine west coasts has a high degree of reliability, and droughts are of rare occurrence.

267. Annual Distribution. With respect to annual distribution of precipitation, the thing to be emphasized is *adequate rainfall at all seasons*, rather than a particular season of marked deficiency. There is no dormant period for vegetation because of lack of rain. In some very marine locations winter may have slightly more precipitation than summer. This winter maxi-

Climatic Data for Representative Marine West-coast Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
					Valentia, Ireland									
Temp.	44	44	45	48	52	57	59	59	57	52	48	45	50.8	15
Precip.	5.5	5.2	4.5	3.7	3.2	3.2	3.8	4.8	4.1	5.6	5.5	6.6	55.6	
					Seattle, Wash.									
Temp.	40	42	45	50	55	60	64	64	59	52	46	42	51.4	24
Precip.	4.9	3.8	3.1	2.4	1.8	1.3	0.6	0.7	1.7	2.8	4.8	5.5	33.4	
					Paris, France									
Temp.	37	39	43	51	56	62	65	64	59	51	43	37	50.5	29
Precip.	1.5	1.2	1.6	1.7	2.1	2.3	2.2	2.2	2.0	2.3	1.8	1.7	22.6	
					Hokitika, New Zealand									
Temp.	60	61	59	55	50	47	45	46	50	53	55	58	53	16
Precip.	9.8	7.3	9.7	9.2	9.8	9.7	9.0	9.4	9.2	11.8	10.6	10.6	116.1	

mum is most marked along the North American Pacific Coast (see data for Seattle) where cool, stable Polar Pacific air masses prevail throughout the summer, resulting in a greatly reduced rainfall at that season. It is likewise a feature of portions of southern Chile.

In spite of the fact that winter is characteristically a wet season, snowfall is not abundant, temperatures being too high on the lowlands for much snow. "Snow is sufficiently rare in most of northwest Europe to be a topic of conversation when it lies more than a few days. . . . " (Kendrew.) Paris has, on the average, 14 snowy days during the year; in the Puget Sound Lowland there are some 10 to 15 such days, and the duration of snow cover is approximately the same length. The snow that falls is wet and heavy, reflecting the relatively high winter temperatures. Upon the ground, it quickly turns to slush, making for unpleasant conditions underfoot. Where mountains border these west coasts, receiving abundant orographic and cyclonic winter precipitation, snowfall is extremely heavy. On the western slopes of the Cascade Range 300 to 400 in. of snow falls on the average each year. Snowfall is likewise heavy on the western slopes of the British Columbia Coast Ranges, the Scandinavian Highlands, the mountains of southern New Zealand, and the southern Andes. In each of these regions the mountain snowfields have in the past given rise to numerous valley glaciers, which in turn have been responsible for the characteristically irregular, fiorded coasts.

268. Origin of Precipitation. Over lowlands precipitation is chiefly frontal or cyclonic in origin, falling as steady long-continued rain, often only drizzle, from a gray, leaden sky. It is in winter that these storms reach their maximum development, and it is at that time of year that cloudy, rainy days are most numerous. In spite of the fact that cyclones are weaker and less numerous in the warm seasons, because the absolute humidity is higher, and the entrance of lows into the continents is facilitated by lower pressures, summer rain may be nearly, if not quite, as great, although it falls in sharper showers on fewer days. Thus at London July has 13 rainy days with 2.4 in. of rain, whereas in January the respective figures are 15 and 1.9. Summers, therefore, are usually brighter and sunnier than winters. The cool marine air masses are not conducive to thunderstorm formation. The North American Pacific Coast records only two to four thunderstorms a year.

A distinguishing feature of the precipitation of these marine climates is the relatively small amount of rain that falls, considering the large number of cloudy, rainy days. Thus although Paris has only 22.6 in. of precipitation, it is spread out over 188 rainy days (average 0.12 in. for each rainy day). Seattle, with 32 in. of precipitation, has 151 rainy days; London has 24.5 in. and 164 rainy days; while Sumburgh Head, on the Shetland Islands, has 36.7 in. spread out over 260 rainy days. London has had 72 rainy days in succession. Where coasts are precipitous, abundant rains of direct or indirect orographic origin supplement those from cyclones and the few convectional storms.

269. Cloudiness and Sunshine. Marine west-coast climate is one of the cloudiest climates of the earth. The American North Pacific Coast region has the highest cloudiness and least sunshine of any part of the United States, the mean annual cloudiness of that region being 60 to 70 per cent. Over wide areas of western Europe cloudiness is greater than 70 per cent, the sun sometimes being hidden for several weeks in succession. Winter, the season of maximum cyclones, is much darker and gloomier than summer. Seattle, which has only 22 per cent of the possible sunshine in November, and 21 per cent in December, has 65 per cent in July and 60 per cent in August, so that summers there are relatively bright and pleasant. Valentia, Ireland, has only 17 per cent of the possible sunshine in December but in May 43 per cent. But even though summers are sunnier than winters, they are still much cloudier than those of Mediterranean climates. Fog and mist are characteristic weather elements of the marine west-coast climate. The American North Pacific Coast has over 40 days with dense fog during the year; Bergen, Norway, has 37.7; and Fanö, Denmark, 53.6.

SEASONAL WEATHER

270. Nonperiodic Weather Element Well Developed. Since cyclonic storms are both numerous and vigorous, it is to be expected that the nonperiodic weather element will dominate. *Winter*, in spite of its mild temperatures, is a stormy period. In coastal locations gales are numerous as one storm follows another in rapid succession. The high seas generated by winter winds are strong enough to make navigation difficult, and unusually severe storms may do serious damage to shipping. The fog and mist make for poor visibility and add to the difficulties of navigation. Precipitation is relatively abundant and very frequent, most of it being in the form of rain rather than snow. Long periods of dark, gloomy, dripping weather are characteristic, so that winters are depressing and hard to endure. Between the frequent cyclones there are occasional sunny days with crisper weather, but these are the exception rather than the rule. Night frosts are not unusual, especially when skies are clear, but ordinarily they are not severe. A pushing westward of polar continental air masses now and then leads to a succession of clear days in which temperatures may remain continuously below freezing.

As the days lengthen with the advance of *spring*, cyclones become fewer and sunshine more abundant. The air is still cool, but the sun is warm, and in western Europe spring is acclaimed the most delightful season. *Summer* temperatures are pleasant for physical well-being, and where sunny days are numerous, as they are in the American Pacific Northwest, a more pleasant summer climate would be hard to find. More especially in the higher middle latitudes, or in very exposed marine locations, chilly, gray, overcast days are numerous even in summer. Rain is still relatively abundant, but it falls on fewer days than in winter. *Autumn* witnesses the equatorward swing of the storm belt again and, as a consequence, a rapid pickup in cloudiness and precipitation.

271. Resource Potentialities of the Marine West-coast Realm. Two of the most significant climatic elements affecting the potential productivity of the marine west-coast realm are (*a*) its unusually long frost-free season, considering the latitude, and (*b*) its relatively mild winters. To be sure, there is a marked dormant season imposed by killing frosts, so that those sensitive and out-of-season crops characteristic of both the dry-summer and the humid subtropics are excluded from this realm. Nevertheless a frost-free period of 6 to 8 months and the relatively mild winters permit many cereal crops to be fall sown and animals can graze out of doors, nearly, if not the entire, 12 months. Large-scale storage of animal feeds for winter use is therefore much less necessary than in the more severe continental climates.

Somewhat offsetting the advantages associated with relatively mild winters and a long frost-free season is the general lack of summer heat, for just as the winters are marine so also are the summers. Thus, while warm-month temperatures of 60 to 65° are ideal for human comfort, and may represent the optimum conditions for physical activity as well, they are not ideal for many crops. Maize, for example, is almost entirely excluded and wheat is difficult to harden and mature. On the other hand, grass finds here almost ideal conditions, so that pastures are usually excellent and hay and forage crops thrive. An adequate amount of rainfall and no season of marked drought are climatic assets of first magnitude. Constancy and dependability of the precipitation year in and year out are reflected in high uniformity of crop yields.

In these mild, humid west-coast regions the original vegetation cover was chiefly forest, and because of the hilly and mountainous nature of large parts of the realm, trees still cover extensive areas. In Europe the original forest was composed largely of broadleaf deciduous trees, with oaks predominating. Conifers, or needle trees, occupied chiefly the highland and sandy areas. Centuries of occupance by civilized peoples has largely removed the forest cover from the plains and even those of the highlands have been greatly modified. In the North American marine west-coast region is the earth's finest coniferous forest which is the world's principal source of high-grade softwood lumber. The Douglas firs of this region are large trees

growing in dense stands so that the yield in lumber per unit area is very large. Forests of the Southern Hemisphere marine west-coast regions are relatively dense and luxuriant, but they are composed of species most of which produce inferior lumber.

272. *Soils and Surface Features.* The gray-brown podzolic soils which are fairly characteristic of lowlands with this type of climate are the best of the world's forest soils. They are by no means the equal of the dark-colored grassland soils, for they have been moderately leached and the supply of organic matter from the forest cover is not abundant. On the other hand, they are distinctly better than the red and yellow soils of the wet tropics and subtropics. Under constant cultivation they deteriorate badly, to be sure, but less rapidly than the other light-colored soils, and with less care and attention they can be kept in good condition and fitted for a variety of crops.

This is the first of the climatic realms where surface and drainage features resulting from continental and mountain glaciation are at all prominent. Except on the European lowlands the glacial features are almost exclusively those resulting from the work of mountain or valley glaciers. Where highlands closely approach the sea as they do in the higher latitudes of Pacific North America, Norway, Scotland, southern Chile, and the southern island of New Zealand, the heavy snowfall is conducive to the development of valley glaciers. A few of these reach the sea even at present, but in those past periods when glaciers were much more extensive, hundreds of valley glaciers reached the ocean along these west coasts in higher middle latitudes. The result is typically fiorded coast lines, ragged in outline, with numerous long, narrow, and steep-walled arms of the sea and innumerable islands. Repetition of this pattern of rugged, island-studded, fiorded coasts and glaciated mountain hinterlands within the four far-separated segments of the marine west-coast realm is extraordinarily striking. In western Europe extensive continental glaciers covered most of the area down to about the Elbe river in Germany and all but the southernmost parts of England and Ireland. On the highlands, composed of resistant crystalline rock, ice scouring removed the weathered rock and soil, grooved and polished the bed rock, and gouged out numerous lake basins. On the lowlands, composed of less resistant rocks, features associated with ice deposition are conspicuous. Among these are numerous lakes and swamps.

CHAPTER 10: *The Humid Microthermal*[1] *Climates (D)*

273. Location. Colder winters, a durable snow cover, longer frost seasons, and larger annual ranges of temperature distinguish the severe microthermal climates from the mesothermal types. This greater severity results primarily from locational differences, with respect to both (*a*) latitude and (*b*) positions on the continents, for microthermal climates lie poleward from the subtropical types and occupy more interior and leeward locations on the great land masses than does the marine west-coast climate (Fig. 52, Plate III). Emphatically, microthermal climates are land controlled and are, therefore, distinctly continental in their characteristics. It is because they are land controlled, being associated with large continents in higher middle latitudes, that they are confined exclusively to the Northern Hemisphere. Only Eurasia and North America are able to produce them. Of the Southern Hemisphere continents, South America alone extends sufficiently far poleward to permit of severe climates, but the narrowness of that land mass south of latitude 35° prevents genuinely severe conditions in spite of the latitude. Microthermal climates are excluded from the western, or windward, coasts because of the dominance there of maritime air masses. They occupy, instead, the interiors of land masses and commonly extend down to tidewater on their leeward or eastern sides, where, in spite of proximity to the sea, modified continental conditions likewise prevail. Unlike the mesothermal climates, those of the microthermal group differ substantially from one another only in degree, and that chiefly in one element, temperature. For this reason the general aspects of microthermal climates as a group are discussed before the individual types of climate are analyzed.

274. Temperature. Because of wide latitudinal spread, there are marked temperature contrasts within those regions classed as microthermal. However, for any particular latitude, these climates are sure to have relatively severe seasons, so that annual ranges are large. Of the two extreme seasons, it is the winter cold, rather than the summer heat, which is most characteristic and distinctive. Nevertheless, summers are warm for the latitude. Not only are the seasons extreme, but they are likewise variable in temperature from one year to another. In marine climates, for instance, one winter is likely to be much like another, but wide departures from the normal seasonal temperature are characteristic of severe continental climates —in extreme instances as much as 30°.

275. *Effects of a Snow Cover upon Temperature.* Only in the microthermal, polar, and highland climates is the snow cover of sufficiently long duration to have a marked effect upon cool-season temperatures. Once a region is overlain by such a white snow mantle, the ground itself ceases to have much influence upon air temperature. Sunlight falling upon snow is largely reflected so that little of the solar energy is effective in heating the ground or the atmosphere. Moreover, although loss of energy by earth radiation goes on very rapidly from the top of a snow surface, the low conductivity of snow tends greatly to retard the flow of heat from the ground below to replace that which is being lost. Observations made at Leningrad, after a fall of 20 in. of loose, dry snow, showed a temperature of $-39°$ at the top of the snow

[1] Micro-, from Greek *mikros*, small. Microthermal, therefore, refers to "small," or low, temperatures.

surface, whereas the ground underneath recorded only 27°, a difference of 66°. Obviously, the effect of a snow cover is markedly to reduce winter temperatures. As spring advances it acts to retard the warming of the air, for the reason that much of the solar energy is expended in melting the snow and ice. On the other hand, the snow cover tends to keep the ground warmer and prevents deep freezing.

276. Precipitation. Although winters are not without precipitation, summer is normally the season of maximum. This seasonal distribution is related to the following conditions: (*a*) The specific humidity or reservoir of water vapor in the atmosphere is much less over the continents during the cold winter than it is in summer when temperatures are much higher. During winter the settling air in the continental thermal anticyclone is likewise conducive to low absolute and specific humidity. (*b*) These same continental anticyclones, which develop over the colder, more northerly parts of the land masses in winter, are areas of diverging air currents, a condition that is antagonistic to the development of fronts and cyclones. In summer, although cyclones may be fewer and weaker, they can, nevertheless, penetrate deeper into the continents. This applies particularly to the more severe microthermal climates, such as the subarctic, where the winter anticyclone is best developed. (*c*) Convection is at a maximum during the warm summer months, for at that season the warm land surface has a tendency to make unstable the air masses flowing over it. In winter, on the other hand, the cold snow surface tends to increase the stability of air masses. (*d*) Consequent upon the seasonal extremes of temperatures, and hence of pressure, a tendency toward a monsoon system of winds is developed, which leads to a strong inflow of tropical maritime air with high rainfall potentialities in summer and to an outflow of dry, cold *cP* air in winter. No such reversal of winds is experienced along marine west coasts in similar latitudes where seasonal temperature extremes are not well developed.

In severe climates with short frost-free seasons it is of the highest importance that rainfall be concentrated in the warm growing season. This is especially true where the total amount of precipitation is relatively modest, as it is over extensive areas within this group of climates. In the tropics it matters not at all when the rain falls since it is constantly hot. Even in the subtropics winter rainfall is effective for plant growth. In the microthermal climates, however, where the severe winters create a completely dormant season for plants, it is highly essential that periods of sufficient heat and sufficient rainfall coincide.

Two principal types of climate are included within the microthermal group, *viz.*, (*a*) humid continental climate, including both warm-summer and cool-summer phases, and (*b*) subarctic climate. The first type, which is an important agricultural climate, characteristically lies on the equatorward margins of the subarctic type, the latter occupying such high latitudes that agriculture ceases to be of great importance.

8. Humid Continental Climates (*Da, Db*)[1]

277. Location. Depending upon the presence or absence of mountain barriers, marine climates of the west coasts change abruptly or gradually into the more severe continental climates of the interiors (Plate III). In North America, where mountain chains parallel the west coasts, the change is sudden and abrupt; on the west European lowlands, on the other hand, it is very gradual. A further contrast distinguishes the two great Northern Hemisphere continents as regards arrangement of climates. In North America, arid and semiarid conditions separate marine west coasts from the continental climates farther east. This results from the abrupt halting of the moisture-bearing winds from the west by mountain barriers, so that to the leeward of the highlands it is dry. A humid marine climate, therefore, passes over directly into a dry continental one. In Eurasia, on the other hand, where, except in Scandinavia, the absence of high mountains permits

[1] The individual letters included in these symbols have been defined in footnotes in earlier chapters.

the deep entrance of marine air into the land mass, humid continental climate lies *both* to the east and to the west of the dry interior. Consequently this type is to be found both in central and eastern Europe, as well as in eastern Asia (Plate III).

In North America the humid continental climates lie poleward of latitude 35 or 40°. On their equatorward margins they pass over into the humid subtropical type and on their poleward sides make contact with subarctic climate. This same arrangement is repeated in eastern Asia. In Europe, on the other hand, Mediterranean replaces humid subtropical climate on the southern frontier (Plate III).

It may be noted with some surprise that severe land-controlled climates should extend eastward to the ocean margins. In part this is due to the fact that the eastern is the leeward side of the continent, and here the ocean is relatively ineffective in greatly modifying temperature conditions. The general west-to-east atmospheric circulation in these latitudes makes the entrance of maritime air into the continent relatively difficult. In addition, the tendency toward monsoons on the eastern sides of large middle-latitude continents tends to accentuate their temperature extremes, making for cold winters and relatively warm summers.

TEMPERATURE

278. Seasons Severe. Warm to hot summers and cold winters are characteristic of the humid continental climate, so that annual ranges are large (Figs. 116 and 121). The monsoonal winds tend only to emphasize further the normal seasonal severity. In general the rigorousness of the climate increases from south to north and likewise from coasts toward the interior. Westerly winds and winter monsoons tend to carry continental air masses down to the eastern littorals, but there is some maritime air of cyclonic or summer-monsoon origin which acts to meliorate conditions slightly, with the result that east coasts have *modified* continental climates. For example, at New York City and Omaha, Neb., in similar latitudes, but the former on the Atlantic Seaboard and the latter deep in the interior, the July temperatures are 74 and 77°, respectively, while their January temperatures are 32 and 22°. The annual range, consequently, is 42° at New York and 55° at Omaha. The higher atmospheric humidity of the air along the seaboard causes the summer heat to be more oppressive and sultry, and the winter cold more raw and penetrating, than are the drier extremes of the interior. The degree of marine modification is greatest where coasts are deeply indented, as, for example, in extreme eastern Canada, in the region of the Maritime Provinces.

279. Seasonal Gradients. Summer and winter in the continental climates present marked contrasts in latitudinal temperature gradients. In the warm season the few isotherms that cross eastern United States are spaced far apart so that one does not experience marked temperature changes in going from north to south, the rate of change being in the neighborhood of 1° for every degree of latitude, or approximately 70 miles. These same weak summer gradients are characteristic of eastern Asia.

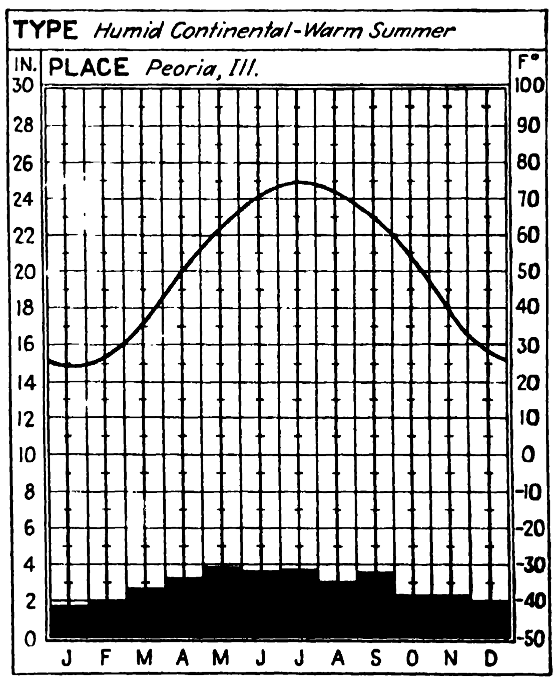

Fig. 116. A representative station of the humid continental warm-summer type in the Corn Belt of the United States.

In winter, on the other hand, temperature changes very rapidly from north to south in eastern United States, the rate being 2.5° for each degree of latitude. Between Harbin, Manchuria, and Hankow, China, there is only 13° difference in July, but there is 42° in January. Between St. Louis and Winnipeg the January contrast amounts to 35°; the July contrast to only 13°. Obviously, there is much more reason for northerners to go south to escape winter cold than for southerners to go north to escape summer heat. Because of the steeper temperature gradients in winter, sudden and marked temperature changes associated with shifts in wind direction are much more common in that season than in summer. These same latitudinal temperature contrasts make the development of cyclonic storms much more likely in winter. The growing season varies greatly in length from north to south in the continental climates, approaching 200 days on the low-latitude margins and decreasing to 100± days on the subarctic side.

PRECIPITATION

280. Amount and Distribution. Rainfall decreases (*a*) from the seaward margins toward the interiors and (*b*) usually toward the higher latitudes as well. Thus along their interior margins the humid continental climates make contact with dry climates, and these interior sections are definitely subhumid. The regions of the prairies, to be found in both interior Eurasia and North America, illustrate this drier subtype. For reasons previously stated, these land-controlled climates are likely to receive their most abundant precipitation in the warm season, although winters are not necessarily dry. More especially it is (*a*) the deep continental interiors and (*b*) the regions of marked monsoonal tendencies, in which summers are emphatically rainier than winters. At Peiping in North China, a station typical of regions having well-developed monsoons, December and January each have only 0.1 in. of precipitation, while July and August have 9.4 and 6.3 in., respectively. Omaha, Neb., typical of an interior regime in North America, has 0.7 in. in January and 4.7 in June. Over much of the United States *east* of the Mississippi, however, the discrepancy between winter and summer precipitation is not so marked. New York City, which receives 3.3 in. in each of the three winter months, has only slightly more, 4.1 and 4.3 in., in July and August, respectively. Its total for the year, however, is 42.5 in.

281. *Early-summer Maximum.* In the more subhumid interior locations the period of maximum rainfall, more often than not, is in early summer and late spring, rather than at the time of greatest heat. This is the case in the Danube Basin and in the western prairie region of the United States. At Beograd (Belgrade), Yugoslavia, June is the wettest month, and May has more precipitation than July. At Omaha, June likewise receives the maximum amount. Lacking a forest mantle, the shallow snow cover of these subhumid lands melts rapidly with the advance of spring, and the dry earth warms quickly under the strong insolation. By May or June, therefore, the lower air has become relatively warm although the upper layers, in which there is a greater seasonal temperature lag, are still cool. Atmospheric instability, and consequently convectional overturning, is therefore greatest in early summer when there is a maximum temperature contrast between lower and upper air. Later in the summer, even though surface temperatures are higher, there is less vertical contrast. Since the largest water requirements of the small-grain cereals occur during the earlier stages of their growth, this early summer maximum of precipitation is of great economic importance.

282. Winter Precipitation. Cool-season precipitation is largely frontal in origin. In North America mT Gulf air masses move poleward up the Mississippi Valley with no relief obstacles to interfere. The cold ground surface chills the Gulf air and consequently stablizes it. Occasionally the tropical air may flow poleward at the ground as far north as Iowa and the southern shores of the Great Lakes. More commonly, however, it comes into conflict with

colder heavier air masses before reaching so far inland and is forced to ascend over them, with widespread precipitation resulting. The North American continental climates, therefore, have a moderate amount of winter precipitation. In northeastern Asia where the winter monsoon is stronger, the *cP* surges more continuous, and the relief barriers formidable, *mT* air is unable to advance so far poleward so that winter precipitation in North China and Manchuria is very meager.

A portion of the winter precipitation is in the form of snow, and a permanent snow cover, varying from a few weeks to several months in duration, is typical. Owing to the fact that (*a*) it takes 5 to 15 in. of snow to equal 1 in. of rain and (*b*) snow tends to remain on the ground whereas rain does not, the smaller total of winter precipitation may be more conspicuous and impressive than summer's greater amount. This contrast is further accentuated by the fact that the cyclonic winter precipitation is continuous over longer periods of time than are the sharper convectional showers of summer. In those parts of northeastern United States and Canada where winter cyclones are particularly numerous and well developed (Great Lakes region, St. Lawrence Valley, New England, and the Canadian Maritime Provinces), snow becomes excessively deep. Thus northern New England and New York have more than 7 ft. of snowfall during an average winter, and the snow cover remains on the ground for more than 4 months. In parts of the Adirondack Mountains 150 in. or more of snow falls annually. Over the American Great Plains, on the other hand, it amounts to only 20 to 30 in.

283. Summer Precipitation. Summer rains, more convectional in origin, often fall in sharp showers from cumulo-nimbus clouds and frequently are accompanied by thunder and lightning. The warm humid *mT* Gulf air that enters deep into the North American continent in summer provides ideal conditions for con-

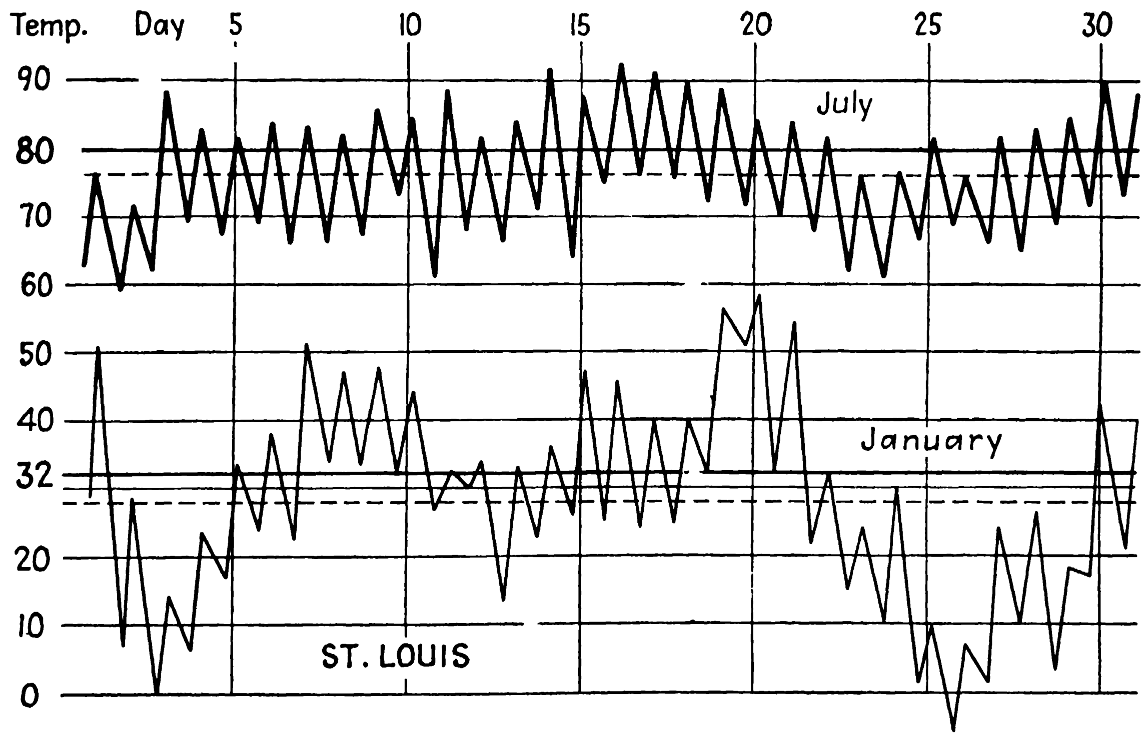

Fig. 117. Note the stronger air-mass control of daily temperatures in winter as compared with summer.

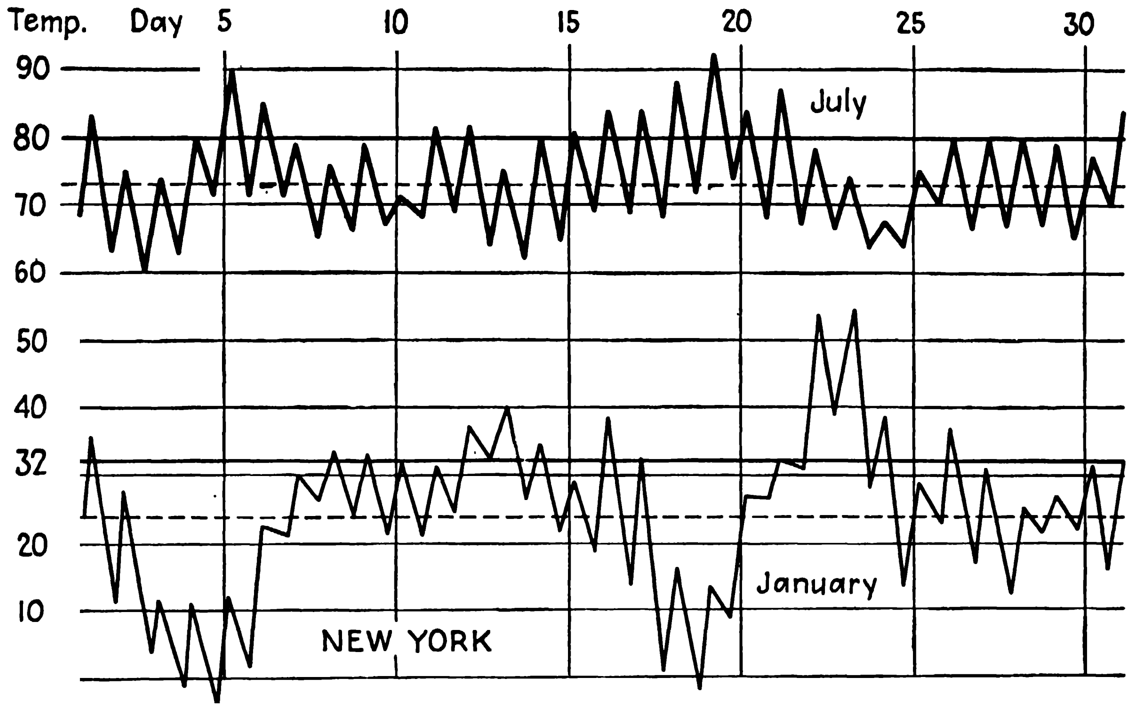

Fig. 118

vectional development over eastern and central United States. In Hungary 61 per cent of the rain in June falls on days with thunderstorms (Kendrew). A fair percentage of the thunderstorms of continental climates are of the local heat variety resulting from excessive surface heating. As a rule the local heat thunderstorms decline and frontal thunderstorms increase in frequency with increasing latitude. Long-continued cyclonic rains falling from gray overcast skies are not absent, to be sure, but this type of weather is less frequent in summer than in the cooler seasons. On the whole, cyclonic weather is most typical of the poleward margins of the continental climates.

SEASONAL WEATHER

284. Nonperiodic Weather Changes Characteristic. In no other types of climate are rapid and marked nonperiodic weather changes so characteristic as in the humid continental, for it is in these regions that the conflict between polar and tropical air masses reaches a maximum development. It is in the cold season, when the sun has retreated farthest south, and with it the storm belt, that the continental climates experience the strongest nonperiodic control of weather. At that season the diurnal sun control is usually subordinate, and weather conditions are dominated by moving cyclones and anticyclones associated with rapidly shifting polar and tropical air masses and the fronts that develop along their boundaries. The daily rise and fall of temperatures with the sun many times are obscured by the larger nonperiodic oscillations caused by invasions of polar and tropical air masses (Figs. 117 and 118). Central and eastern United States, which are freely open to the movements of air masses both from north and south, are regions of unusual storminess. Storm control is less marked in eastern Asia. In the deep interiors and higher middle latitudes of the continents the effects of the winter continental anticyclone are more pronounced, and the weather as a consequence is drier, colder, and somewhat less fickle. In summer, throughout the humid continental climates, air masses are more stagnant, fronts are fewer,

United States and China, the figures being below 75° more often than above (Fig. 119).

288. Winters are likely to be relatively cold but with numerous spells of mild, disagreeable, rainy weather sandwiched in between the periods of cold. The average January temperature at Urbana is 27°, and the average of the daily minima is only 18°, although 25° below zero has been known to occur (Figs. 117 and 118). St. Louis has an average January temperature of 32°; București (Bucharest), Rumania, 27°; and Peiping, China, 24°. Monthly averages, however, are not of great value for describing winter temperatures, since the latter are composed of such wide variants. Since the warm-summer phase is bounded by such opposite temperature conditions on its northern and southern frontiers, it is to be expected that marked temperature contrasts can be produced by polar and tropical air-mass invasions.

Climatic Data for Representative Stations in the Warm-summer Subtype

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Peoria, Ill.								
Temp.	24	28	40	51	62	71	75	73	65	53	39	28	51	52
Precip.	1.8	2.0	2.7	3.3	3.9	3.8	3.8	3.2	3.8	2.4	2.4	2.0	34.9	
						New York City								
Temp.	31	31	39	49	60	69	74	72	67	56	44	34	52	43
Precip.	3.3	3.3	3.4	3.3	3.4	3.4	4.1	4.3	3.4	3.4	3.4	3.3	42.0	
						București (Bucharest), Rumania								
Temp.	26	29	40	52	61	68	73	71	64	54	41	30	51	48
Precip.	1.2	1.1	1.7	2.0	2.5	3.3	2.8	1.9	1.5	1.5	1.9	1.7	23.0	
						Peiping, China								
Temp.	24	29	41	57	68	76	79	77	68	55	39	27	53	55
Precip.	0.1	0.2	0.2	0.6	1.4	3.0	9.4	6.3	2.6	0.6	0.3	0.1	24.9	

Precipitation

289. Amount. In terms of the total amount of precipitation, most of the world regions possessing humid continental climate with warm summers suffer from too little, rather than too much, rainfall. Thus parts of the North China Plain, the Danube Lowlands of Europe, and the western portion of this climatic region in the United States are all subhumid in character, with grass as the prevailing type of natural vegetation. It is chiefly northern Japan, Korea, and the eastern and central portions of the American region that are fortunate in having more than 30 in. of precipitation. Occasional crop failures as a result of drought are characteristic of the subhumid portions. This is especially true in North China where, because of the very dense population, drought years are likewise famine years.

290. Annual Distribution. Summer rains predominate, the warm-season maximum being particularly marked in the more subhumid portions or where monsoons prevail (Fig. 116). This is fortunate, for in regions with severe winters, and where precipitation is none too bountiful, it is especially necessary for rainfall to be concentrated in the growing season for crops. The warm summertime convectional rains have the advantage of permitting a maximum of sunshine and heat along with an abundance of rain. Such a condition is ideal for the corn crop. At Peoria, Ill., though there is a distinct concentration of rainfall in the warm months, it is this same season that has the largest amount of sunshine. For example, July has 3.8 in. of precipitation, falling on 10 rainy days, and 75 per cent of the possible sunshine. January, with only 1.8 in. of precipitation and 9 rainy days, has only 47 per cent of the possible sunshine. Days with thunderstorms are numerous, averaging 40 to 60 a year in the American Corn Belt.

Winter precipitation is usually less than that of summer Only in Japan, Korea, parts of central Europe, and central and eastern United States can winters be classed as distinctly humid. North China represents the opposite extreme, for at Peiping the combined precipitation of the three winter months is only 0.4 in., as compared with 18.7 in. for the three summer months. This reflects the well-developed system of monsoon

winds which dominates eastern Asia. The western margins of the American Corn Belt also have a relatively marked winter minimum in precipitation, with only 2 to 4 in. during December to February.

A portion of the winter precipitation falls as snow, although it is usually less than one-half the season's total. Over the American Corn Belt snow falls on 20 to 30 days of the year, the total amounting to 10 to 40 in. The number of days with snow cover varies from 10± on the southern margin to 60+ on the poleward side (Fig. 120). The Danube plains normally have 20 to 30 days with snow.

8*b*. HUMID CONTINENTAL CLIMATE WITH COOL SUMMER (*Db*)

291. Location. This more severe phase of humid continental climate lies on the poleward side of the warm-summer subtype and between it and subarctic climate (Fig. 82). It is sometimes designated as the "spring-wheat" type, since that important commercial crop reaches its most specialized development in the subhumid parts of the cool-summer phase. This is scarcely the case in the more humid parts, however. In North America the type is found in general east of the 100th meridian and includes the northern tier of states in the United States and portions of southern Canada as well (Plate III). In Eurasia it includes eastern Germany, Poland, and a large part of the central Russian plain between latitudes 50 and 60°+. Beyond the Urals it extends on into Siberia as a narrower strip in the vicinity of latitude 55°. In much of Soviet Russia it is terminated on the south by steppe climate. The third large representative area is in northeastern Asia, more especially northern Manchuria, southeastern Siberia, and the island of Hokkaido in Japan.

Temperature

292. Temperatures Relatively Extreme. Because of its characteristic location in higher

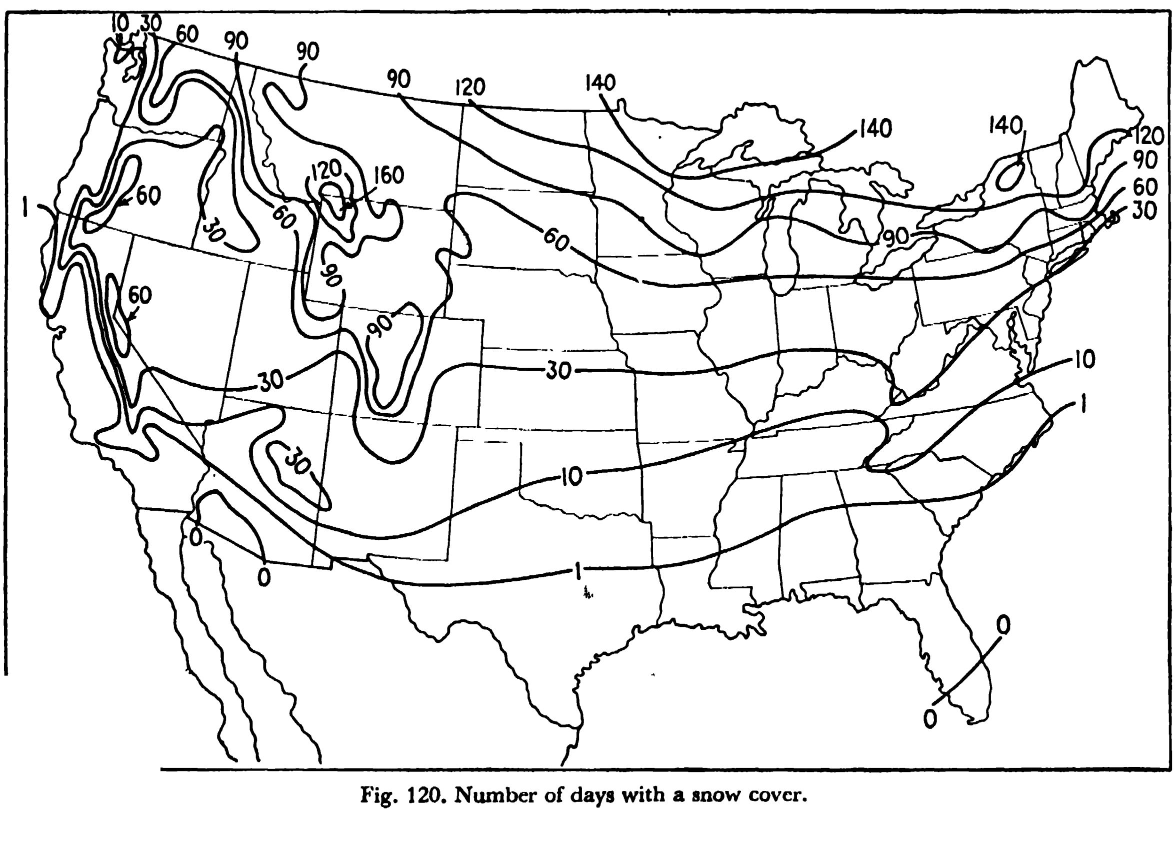

Fig. 120. Number of days with a snow cover.

latitudes, temperatures are somewhat lower than in the warm-summer phase farther south (Fig. 121). This is much more emphatically the case with winter than with summer, for while the hot months are only 5 to 10° cooler, average winter-month temperatures are 10 to 30° lower. It is the severer winters, then, that chiefly account for the larger annual ranges. Summers are usually warm for a few months, the average July temperatures being a few degrees above or below 70° (St. Paul, 72°; Montreal, 69°; Moskva (Moscow), 66°; Barnaul, Siberia, 67°; Harbin, Manchuria, 72°). But the climate is handicapped by reason of the relatively short duration of summer. Thus, while Indianapolis (warm-summer phase) has 7 months the average temperatures of which are over 50°, St. Paul and Winnipeg have only 5. Frost comes early and remains late, so that the growing season is only 3+ to 5 months in length, which is insufficient for a number of crops. Offsetting somewhat the two handicaps of shorter and cooler summers is the advantage of the longer days that prevail in the higher latitudes so that the amount of solar energy received per unit area (turbidity and cloudiness considered) on June 21 is considerably higher in latitudes 50°–60°N. than it is at 0°–10°. At the time of the Northern Hemisphere summer solstice, Winnipeg has a daily period of insolation which is more than one hour longer than that of St. Louis.

Midday temperatures in July are likely to be warm to hot, especially when the sun is shining. Overcast days, on the other hand, are inclined to be chilly. It is not unusual to experience summer days with temperatures of 90° and above (Fig. 122). Hot waves, similar in origin to those in the regions farther south, do occur, but they are usually not quite so severe or so long. There are, on the other hand, more spells of cool, cloudy weather than in the warm-summer phase, for, in the United States at least, this climatic type is closer to the tracks of summer cyclones. It is these cool spells that draw down the general summer average.

Winter is the dominant season. At Barnaul the January average is −2°; Harbin, Manchuria, −2°; Bismarck, N.D., 9°; Montreal, 13°; and Warszawa (Warsaw), 26°. But these averages are composed of very unlike temperature elements, since the succession of cyclones and anticyclones brings much subzero weather as well as some that is distinctly above freezing (Fig. 122). Winters differ greatly from year to year in the continental climates. Thus a recent January at Bismarck had only one day with temperatures below −10°, as compared with 14 in January of the previous year. Large storm-controlled temperature fluctuations within a short period of time are likewise characteristic, changes of 40° within 24 hr. being relatively common. These temperature fluctuations and variations are associated with advances and retreats of polar and tropical air masses. In the western portions of Europe's cool-summer continental climate (southern Sweden, Poland, Germany), although summer temperatures are as low, if not lower than in North America and Asia, the winter-month temperatures are distinctly higher. This reflects the easy entrance into Europe of maritime air masses from the Atlantic.

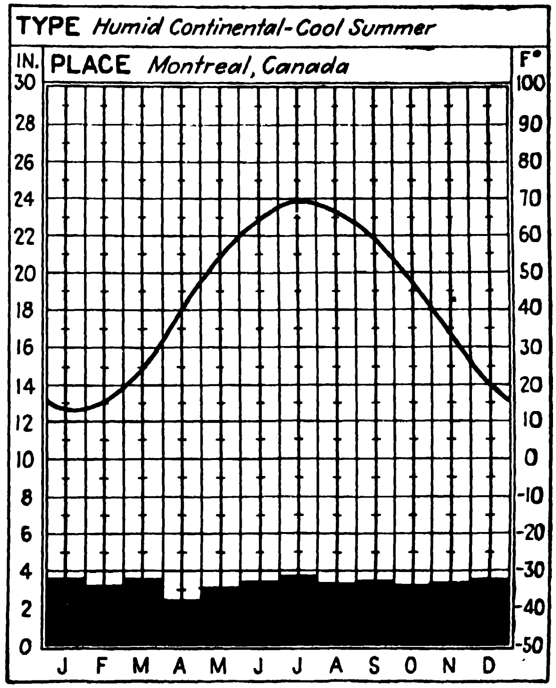

Fig. 121

Climatic Data for Representative Stations in the Cool-summer Subtype

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Madison, Wis. (marginal in location)								
Temp.	17	20	31	46	58	67	72	70	62	50	35	23	46	55
Precip.	1.2	1.3	1.9	2.6	3.7	3.4	3.5	3.3	4.1	2.3	2.0	1.4	30.6	
						Montreal, Canada								
Temp.	13	15	25	41	55	65	69	67	59	47	33	19	42	56
Precip.	3.7	3.2	3.7	2.4	3.1	3.5	3.8	3.4	3.5	3.3	3.4	3.7	41	
						Moskva (Moscow), Soviet Union								
Temp.	12	15	23	38	53	62	66	63	52	40	28	17	39	54
Precip.	1.1	1.0	1.2	1.5	1.9	2.0	2.8	2.9	2.2	1.4	1.6	1.5	21.1	
						Harbin, Manchuria								
Temp.	−2	5	24	42	56	66	72	69	58	40	21	3	38	74
Precip.	0.1	0.2	0.4	0.9	1.7	3.8	4.5	4.1	1.8	1.3	0.3	0.2	19.3	

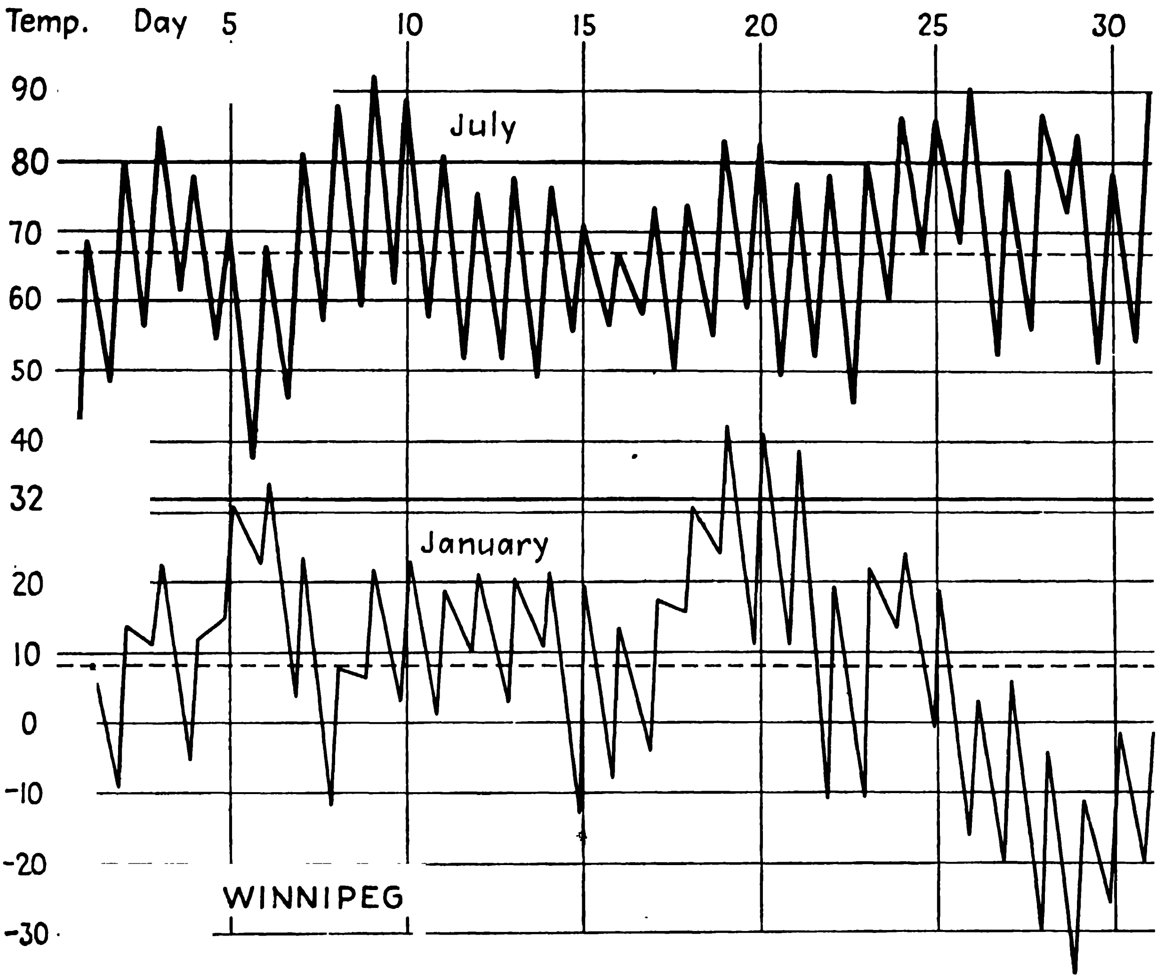

Fig. 122. A representative station in humid continental climate with cool summers.

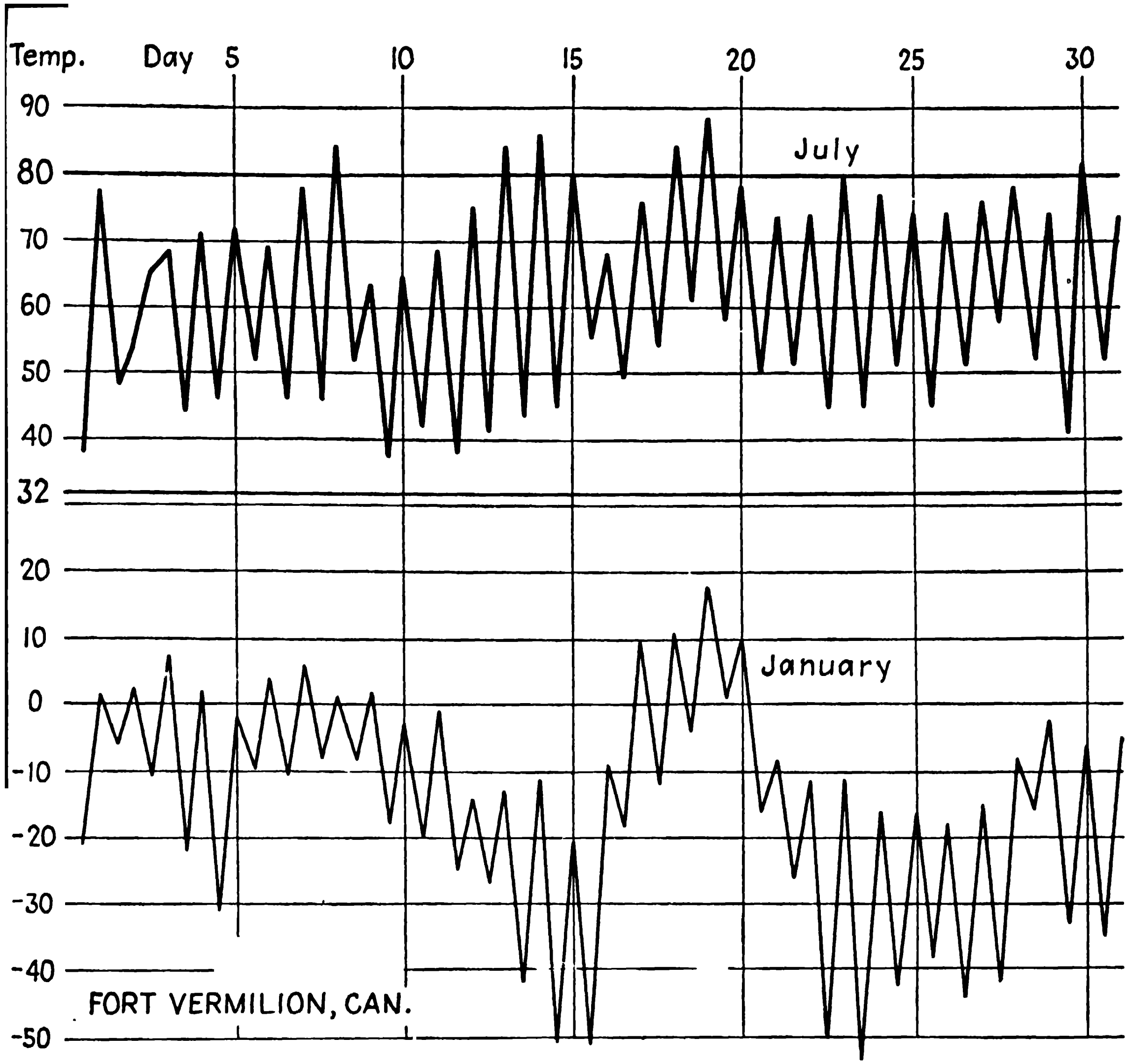

Fig. 127. A subarctic station in Canada.

ment, so that at present much of the subarctic has only a meager sprinkling of frontier farmers and of people exploiting the mineral, forest, and wild-animal resources.

300. Winter follows on the heels of summer with only a very brief intervening autumn season. Frosts may arrive in late August, and ice begins to form on pools in September. By the middle of October navigation for small craft is made difficult on the subarctic lakes of Canada. At Verkhoyansk, Siberia, the mean temperature drops 40° from October to November. Subarctic Siberia holds the records for minimum temperatures at low elevations, even lower than those of polar climates. Verkhoyansk, in the northeastern part, boasts an average January temperature of 59° below zero, while an absolute minimum of −90° was recorded in February, 1892. This, of course, is an extreme case. At Yakutsk, however, where July has an average temperature of 66°, the January mean drops to approximately −46°, producing an annual range of 112°. For 7 months at Yakutsk the average temperatures are below freezing, and

during 5 months they are below zero. No other type of climate can show such contrasts between summer and winter temperatures.

Concerning the Siberian winter, Hann writes:

> It is not possible to describe the terrible cold one has to endure; one has to experience it to appreciate it. The quicksilver freezes solid and can be cut and hammered like lead; iron becomes brittle, and the hatchet breaks like glass; wood, depending upon the degree of moisture in it, becomes harder than iron and withstands the ax so that only completely dry wood can be split. Every step in the dry snow can be heard for long distances; the bursting of the ice cover and the frozen ground sound like the cannonading of distant batteries.

Subarctic winters in North America are not quite so severe as are those of Siberia. This comes about in part as a result of Asia's being a broader land mass. Moreover it contains no such extensive arm of the sea as is Hudson Bay in North America. In addition the mountains of eastern Siberia retard the eastward flow of the cold continental air, thereby aiding in an excessive accumulation of cold air over the continent. the short summers. The depth to which frost penetrates and the depth of the summer thaw vary greatly from one part of the subarctic lands to another. Cleveland Abbe notes the case of a mine in the Klondike (Yukon) which passed out of the permanently frozen zone at a depth of 220 ft.

Just as long days are characteristic of subarctic summers, so long nights are characteristic of the winters. For example, on Dec. 21 all places on the 60°N. parallel can receive a maximum of only 5.7 hr. of sunshine, while on latitude 65°N. the maximum is only 3.3 hr. These long daily periods of darkness are not only depressing and hard to bear, but they are, in a considerable measure, responsible for the low winter temperatures.

Spring, like autumn, is a short and inconspicuous season. At Yakutsk there is a difference of 25° between the mean temperatures of April and May, and 18° between May and June. The average April temperature at Yakutsk is like that of Madison, Wis., in January, while May is only 4 to 5° lower than April at Madison.

Climatic Data for Representative Subarctic Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Fort Vermilion, Alberta, Canada (58°27′N.)														
Temp.	−14	−6	8	30	47	55	60	57	46	32	10	−4	27	74
Precip.	0.6	0.3	0.5	0.7	1.0	1.9	2.1	2.1	1.4	0.7	0.5	0.4	12.3	
Moose Factory, Canada (51°16′N.)														
Temp.	−4	−2	10	28	42	54	61	59	51	39	22	5	30	66
Precip.	1.3	0.9	1.1	1.0	1.8	2.2	2.4	3.3	2.9	1.8	1.1	1.1	21.0	
Yakutsk, Siberia, Soviet Union														
Temp.	−46	−35	−10	16	41	59	66	60	42	16	−21	−41	12	112
Precip.	0.9	0.2	0.4	0.6	1.1	2.1	1.7	2.6	1.2	1.4	0.6	0.9	13.7	

Representative stations such as Churchill, Dawson, and Fort Good Hope show average January temperatures of −20, −22, and −32°, respectively. At Dawson, in the Yukon, at 64°3′N., the thermometer, on an average January night, falls to approximately −29° and rises to nearly −16° during the warmest hours of the day (Figs. 126 and 127).

The excessive and long-continued cold of the subarctic winters causes large parts of taiga regions to be permanently frozen down to great depths. Over extensive areas of the subarctic lands only the upper few feet thaw out during

PRECIPITATION AND HUMIDITY

301. Amount. Precipitation in subarctic climates is usually meager (Fig. 124). Over much of the Siberian taiga it is no more than 15 in., while most of subarctic Canada receives less than 20, and parts receive less than 15 in. The modest precipitation is related to (*a*) the low temperatures and associated low specific humidity, (*b*) the well-developed winter anticyclone with its settling air and diverging wind systems, and (*c*) the great breadth of the land masses in the subarctic latitudes. It is principally along the oceanic margins in both Eurasia and North

America that rainfall exceeds 20 in. In most middle-latitude climates these small amounts, characteristic of the taiga, would be classed as semiarid, but where such low temperatures and, therefore, low evaporation rates prevail, and where the ground is frozen so much of the year, the precipitation is sufficient for forest growth.

302. Annual Distribution. Precipitation is concentrated in the warmer months. At Yakutsk, where the total annual rainfall is 13.7 in., August is the wettest month with 2.6 in., and February the driest with 0.2 in. At Dawson in the Yukon the total is 12.5 in., with 1.5 in July and 0.8 in January (0.7 in. in February and 0.5 in March). It is over east-central Siberia, in particular, that winters are especially dry, the three winter months there having only 10 per cent of the annual precipitation, while the three summer months have 58 per cent. This is the region of most intense cold and highest winter pressures.

Over lowlands the meager winter precipitation, practically all of it in the form of snow, is cyclonic in origin. The few fronts that cross these areas yield sufficient precipitation, in the form of relatively dry, hard, snow, so that a permanent snow cover, lasting 5 to 7 months, is common. Because of the shelter provided by the forest, little melting or evaporation occurs, so that the winter snows accumulate to a depth of 2 to 3 ft. in the taiga. This same protection by the forest leads to slow melting of the snow cover in spring. In east-central Siberia, winter precipitation is so meager that sleighing is sometimes difficult.

Summer, the season of maximum surface heating, steepest vertical temperature gradients, and highest humidity, provides conditions that are relatively most favorable for rainfall. Warm-season precipitation is largely frontal in origin. Thunderstorms are not numerous, the total number in the Mackenzie Valley of Canada being in the neighborhood of 5 to 10 a year. They are associated with the hottest spells, when convection is at a maximum. Fort Vermilion, in the Mackenzie Valley, has on the average 5.3 rainy days in June, 9.1 in July, and 7.5 in August. Comparable data for Dawson, in the Yukon, are 11.7, 10.3, and 10.9 (Koeppe).

303. Resource Potentialities of the Subarctic Realm. In spite of the fact that this is one of the most extensive of the earth's geographic realms, it is also one of the least productive. Like the dry lands, and much of the wet tropics, the subarctic realm is coincident with relatively blank areas on the world-population map. The extractive industries, such as hunting, fishing, mining, and logging, which are of more than usual importance, are capable of supporting only a meager population. The landscape, therefore, is one composed predominantly of natural features; man has left but a faint imprint.

In productive capacity the realm is fundamentally handicapped by a niggardly climate which sets very definite and low limits upon agricultural development. The primary handicaps are associated with (*a*) the briefness of the summers and (*b*) the relatively low summer temperatures. It is obviously impossible to draw a line that accurately defines the northern limits of agriculture as set by temperature conditions. Some quick-maturing vegetables grow almost as far poleward as the Arctic Circle. In certain favorable years both wheat and barley have been matured in 70 to 80 days, but summer frosts in any year may prevent a harvest. At present however, commercially successful agriculture is not likely in regions where the frost-free season is less than 80 or 90 days, and this condition prevails in all except the most southerly portions of the subarctic realm. Along the southern margins of the taiga, in both Eurasia and North America, are two of the great frontier regions of the earth where human beings are struggling to push their agricultural settlements farther poleward. But the progress is slow and is probably destined to remain so.

Subarctic Eurasia and North America are covered by what is largely a virgin coniferous forest. In their immensity and monotony these subarctic forests are like the sea, and travelers are impressed with their emptiness and silence. Even animal life is not abundant. They are among the largest and least known wildernesses

of the earth. Conifers usually occupy in the neighborhood of 75 per cent of the forest area with such deciduous trees as birch, poplar, willow, and alder comprising most of the remainder. In both continents spruce and fir are the dominant trees, although larch and pine are plentiful. Neither in the size of the trees nor in the density of the stand is taiga forest impressive, so that it does not represent nearly so great a potential supply of forest products as its area might seem to indicate. In the ice-scoured Canadian subarctic extensive areas of lake, swamp, and bare rock are practically without forest. Subarctic timber is probably much more universally valuable for firewood and pulpwood than for good lumber. Moreover, the inaccessibility of these northern forests involving the severe handicap of distance to world markets greatly reduces their resource value.

The subarctic forest lands are the home of many of the earth's most important fur-bearing animals and are the source of a large proportion of the wild pelts taken annually. The lakes and swamps and the forest cover provide the satisfactory habitat conditions for various types of animals, while the long and severe winters induce thick, heavy pelts. In many parts the forest animals are more valuable than the vegetation cover under which they live. Ruthless hunting and trapping have, however, caused the numbers of fur-bearing animals to dwindle alarmingly.

An impoverished soil environment is characteristic of the subarctic realm. This infertile soil, combined with a climate of low potentialities, causes the subarctic lands to offer what appear to be almost insurmountable difficulties to the agricultural settler. The needles from the coniferous forest provide a very meager supply of organic material for the soil, while the ground water, high in organic acids derived from the raw humus, results in an excessive leaching of the soil minerals.

After climate and soils, the third ranking handicap to agricultural settlement within the subarctic realm is deficient drainage. This prevalence of poorly drained land is partly the result of a permanently frozen subsoil, a condition which prevails throughout the higher latitudes of the realm. Over most of subarctic North America and in Scandinavia, Finland, and western Soviet Russia the abundance of lakes and swamps is a consequence of continental glaciation. The name Finland, derived from "fen land," suggests the prevalence of lake and marsh in that country where they occupy about one-third of the entire area. Still another cause of the realm's deficient drainage is associated with the fact that many of its streams flow poleward into the Arctic Ocean. Such rivers thaw out in their upper and middle courses while the lower courses are still frozen and therefore unable to carry the drainage waters. As a result, where lowlands prevail, widespread spring inundations are the result.

CHAPTER 11: *Polar Climates and Highland Climates*

Polar Climates (*E*)

304. As the tropics are characterized by lack of a cool season, so the polar regions are wanting in a period of warmth. It is the prevalence of monotonous heat that typifies the low latitudes. In the high latitudes monotonous and long-continued cold is the greatest handicap. Certain explorers to the contrary, the polar areas cannot be made to appear warm by noting that occasional days with temperatures over 80° have been experienced beyond the Arctic Circle. "One swallow does not make a summer," nor do a few warm days determine the general climatic character of a region.

305. Phenomena of Light and Darkness. A distinctive feature of the polar climates is their peculiarities with respect to periods of light and darkness. At the poles the sun is out of sight entirely for approximately 6 months, while for an equal period it is constantly above the horizon, although never very high in the heavens, so that insolation is weak. At the Arctic and Antarctic Circles, which lie near the equatorward margins of polar climates, the daily period of sunlight varies from 24 hr. at the time of the summer solstice to a complete lack of sunlight at the winter solstice. At points between the poles and the $66\frac{1}{2}°$ parallels the lengths of the periods of sunlight, and absence of sunlight, are intermediate in character between the two extremes noted.

306. Locations and Boundaries. Polar climates are largely confined to the high latitudes of the earth. Somewhat similar conditions can be found at high altitudes in a great variety of latitudes. But these latter regions of continuous cold usually are very isolated and fragmentary and in this book are included within the group designated as highland climates.

The poleward limit of forest is usually accepted as marking the boundary separating the cold climates from those of the intermediate latitudes. In continental locations this vegetation boundary approximately coincides with the isotherm of 50° for the *warmest month*, so that this seasonal isotherm is commonly employed in defining the outer margins of the polar climates.[1] It is significant that, while for the boundary of the humid tropics a *cool-month* isotherm is employed, a *warm-month* isotherm serves in the same way for polar climates (Fig. 82). It suggests that, while a period of coolness is of critical importance for plants and animals in the low latitudes, a period of warmth is much more significant in high latitudes. In the Southern Hemisphere the only conspicuous land area possessed of polar climates is the ice-covered Antarctic continent. In the Northern Hemisphere it is the Arctic Sea borderlands of Eurasia and North America, together with extensive island groups north of both continents and ice-covered Greenland, which are included.

307. Arctic and Antarctic. Since the Arctic is almost a landlocked sea, while the Antarctic is a seagirt land, certain important climatic differences are to be expected between the two regions. As a consequence of its single land mass being centered at the Pole and surrounded on all sides by extensive oceans of uniform temperature, the Antarctic shows much greater uniformity and simplicity in its climate than

[1] In order to exclude certain cool marine climates which are not distinctly polar in nature, the definition should further stipulate a mean annual temperature of 32° or below.

does the Arctic. Wind and pressure systems are symmetrically developed about the South Pole, and there is little change in these elements throughout the year, whereas lack of symmetry and seasonal variations in these controls are characteristic of the north polar regions.

308. Temperature and Precipitation. Polar climates claim the distinction of having the lowest *mean annual*, as well as the lowest *summer*, temperatures for any part of the earth. In spite of the long duration of sunshine in summer, temperatures remain low, the rays being too oblique to be genuinely effective. Moreover, much of the solar energy is reflected by the snow and ice or is consumed in melting the snow cover and evaporating the water, so that neither the land surface nor the air adjacent to it becomes warm. Winters are bitterly cold, but there is some doubt as to whether the thermometer ever sinks as low in the polar regions as it does in the subarctic climate of northeastern Siberia. In spite of the cool summers, winter cold is sufficiently severe to develop large annual ranges.

Precipitation is meager throughout the high latitudes. Over large parts of the land areas it is less than 10 in. But in spite of its meagerness, the low evaporation permits of some runoff, part of it in the form of glaciers. It is because of the low evaporation and the small amount of melting that great permanent snow and ice fields several thousand feet thick have been able to accumulate on Greenland and the Antarctic continent, and this in spite of the low precipitation. A dearth of polar precipitation does not seem unusual when one considers the prevailingly low absolute humidity which must accompany the low temperatures. The reservoir of water vapor is small at all times. Moreover, in these latitudes there is a general settling of the cold upper air masses which creates a condition unfavorable to condensation. Precipitation is usually heavier in the warmer months when the moisture supply is most abundant.

309. Tundra and Ice Caps. Polar climates are usually subdivided into two types, with the *warmest month* isotherm of 32° serving as the boundary between them. Where the average temperatures of all months are below freezing, the growth of vegetation is impossible, and a permanent snow-and-ice cover prevails. These are the *ice-cap climates*. Where one or more of the warm-season months has an average temperature above 32° (but not over 50°) so that the ground is free from snow for a short period, and a meager and lowly vegetation cover is possible, the climate is designated as *tundra*.

10. Tundra Climate (*ET*)[1]

310. Location. Tundra climate is transitional in character between the ice caps, or regions of perpetual snow and ice, on the one hand, and middle-latitude climates, usually subarctic, on the other (Fig. 82, Plate III). Its accepted equatorward and poleward boundaries are the warmest month isotherms of 50 and 32°, respectively, which, as indicated previously, are reasonably coincident with important vegetation boundaries.

Tundra climate over land areas is almost exclusively confined to the Northern Hemisphere. In the Antarctic, ocean prevails in those latitudes where the tundra would normally develop. Only the most northerly fringes of the Antarctic continent, and certain small Antarctic islands, have sufficiently warm summers for them to be included. The most extensive tundra areas are the Arctic Sea margins of both North America and Eurasia. Most of the Arctic archipelago of the former continent, as well as the coastal fringe of Greenland, is likewise included.

TEMPERATURE

311. Summer. Long cold winters and very short cool summers are the rule (Fig. 128). By the definition of boundaries for tundra climate, previously stated, the average temperature of the warmest month can be no lower than 32° and no higher than 50°. The cool character of the summer is therefore relatively fixed. Raw and chilly, the warmest months of the tundra resemble March and April in southern Wisconsin and are like January in the American Cotton Belt. Usually only 2 to 4 months have average temperatures above freezing, and killing

[1] *ET*, warmest month below 50° (10°C.) but above 32° (0°C.).

frost is likely to occur at any time. Along coasts, where water, ice, and land are in close proximity, fog is very prevalent. These fogs may last for days at a time and are extraordinarily depressing. Under the influence of unusually long summer days, the snow cover begins to disappear in May, and the lakes are usually rid of their ice cover in June. Because of the permanently frozen subsoil, subsurface drainage is deficient, and bog and swamp are prevalent. Myriads of mosquitoes and black flies make life almost unbearable for man and beast alike during the summer period of wet earth.

At Ponds Inlet, Canada, a tundra station at 72°43′N., where the average July temperature is 42°, the thermometer in that month rises to about 49° during the warmest hours of the day and, on the average, sinks to 35 or 36° at night. Daily ranges in summer are relatively small, for the sun is above the horizon for all or a greater part of the 24-hr. period. On most July nights no frost occurs, but on the other hand it is not

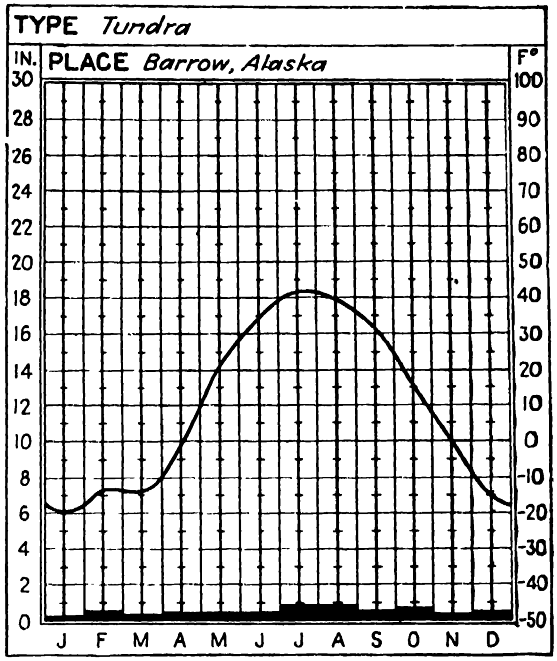

Fig. 128

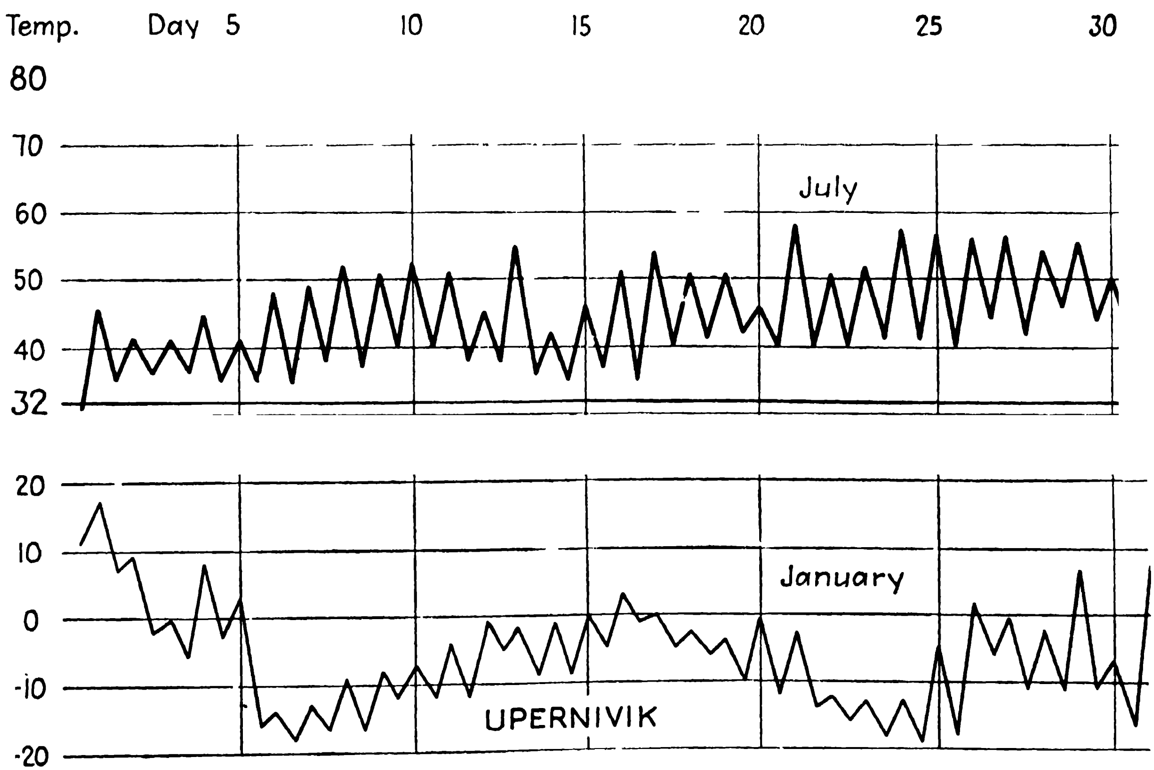

Fig. 129. A tundra station in Greenland.

unusual for the thermometer to slip a few degrees below freezing (Fig. 129). Warm days occur now and then, Ponds Inlet having recorded, on at least one occasion, a temperature of 77°.

312. Winter. While summer temperatures are not greatly different from one tundra region to another, there are greater variations in the winters. Thus along the Arctic coasts of Siberia, average January and February temperatures are in the neighborhood of −35 or −40°, and it is appreciably colder farther inland. At this season winds in general are from the bitterly cold subarctic region to the south, and these importations serve only further to intensify the severity of temperatures in the tundra. Along the Arctic borderlands of North America winters are not quite so severe. A coastal station in Labrador shows a January mean of −8°; Ponds Inlet in Canada records an average of −28° for January, −30° for February, and even −24° for March (Fig. 128). At the latter station 5 months, November to March, have average temperatures below zero, while 9 are below freezing.

Climatic Data for Representative Tundra Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Sagastyr, Siberia, Soviet Union (73°N., 124°E.)														
Temp.	−34	−36	−30	−7	15	32	41	38	33	6	−16	−28	1	77
Precip.	0.1	0.1	0.0	0.0	0.2	0.4	0.3	1.4	0.4	0.1	0.1	0.2	3.3	
Upernivik, Western Greenland (73°N., 56°W.)														
Temp.	−7	−10	−6	6	25	35	41	41	33	25	14	1	16	61
Precip.	0.4	0.4	0.6	0.6	0.6	0.6	1.0	1.1	1.0	1.1	1.1	0.5	9.2	

PRECIPITATION

313. Amount and Distribution. Over most of the tundra lands precipitation is not over 10 or 12 in. (Fig. 128). In portions of eastern Arctic Canada, particularly Labrador peninsula, it is somewhat greater. Low summer temperatures and winter anticyclonic conditions are, in general, not conducive to abundant condensation, while convectional effects are largely absent. Summer and autumn, the warmest seasons, are likewise the periods of maximum precipitation throughout the tundra as a whole. In the more marine locations, where cyclones are greater in number, fall and winter may show larger totals than summer. Precipitation is principally cyclonic in origin. Much of that which falls in the warm season is in the form of rain, with occasional wet snows. The meager winter snowfall is usually dry and powdery in character so that it forms a very compact cover. It is only this very compact snow, 2 in. of which may equal an inch of rain, that the Eskimos use in constructing their igloos. The actual amount of dry sandlike snow that falls is not easy to measure, since it is often accompanied by strong blizzard winds which heap it up in depressions and on the lee sides of hills, while at the same time sweeping bare the exposed surfaces. There are no forests, as in the taiga, to break the force of the wind and hold the snow cover. Stefansson estimates that 75 to 90 per cent of the surfaces of the Arctic lands is nearly free of snow at all seasons. Both as a result of the small amount of snow and as a result of its strong tendency to drift, sledging commonly is difficult.

11. Ice-cap Climate (*EF*) [1]

This least well known among the world's climatic types is characteristically developed over the great permanent continental ice sheets of Antarctica and Greenland and over the perpetually frozen ocean in the vicinity of the North Pole. Only fragmentary data have been obtained from these deserts of snow and ice where the average temperature of no month rises above freezing.

314. Temperature. The mean annual temperature of interior Greenland has been calculated to be −26°; that of the South Pole −22 to −31°; that of the North Pole −9°. These, without doubt, are the lowest annual temperatures for any portion of the earth. Observed temperatures for the *warmest* months in the neighborhood of the South Pole, at the time of continuous insolation, were −9° (December) and −19° (January). A temperature of −58° has been recorded in the Antarctic continent

[1] *EF*, warmest month below 32° (0°C.).

in this season. Unquestionably, therefore, Antarctica has the distinction of being the earth's coldest spot in summer. While the North Pole and interior Greenland are certainly below freezing in July and August, they are far from being as cold as the South Polar plateau at the time of continuous day. To be sure, the figures given above are for interior portions of Antarctica and hence represent extreme conditions. Along the margins of that continent warm-month temperatures are considerably milder (McMurdo South, 25°; Little America, 21°).

During the period when the sun is constantly below the horizon, excessively cold weather prevails, although exact and reliable data are not available. On the Antarctic plateau the average winter-month temperatures are probably in the neighborhood of 35 to 45° below zero. It is not impossible that in some of the wind-protected depressions of that region, cold-month and minimum temperatures are as low as those of subarctic northeastern Siberia.

The inner portions of the ice caps, where permanent anticyclones with settling air prevail, are probably regions relatively free from storms and violent winds. Certain of their marginal areas, however, where there is a precipitous descent of cold air from the inland-ice plateau, are characterized by furious gales. But these regions of excessive storminess appear to be local rather than widespread. It is likely that storminess increases from the centers toward the circumferences of the ice caps.

Climatic Data for a Representative Ice-cap Station

Little America, Antarctic Continent (79°S., 164°W.)

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	22	(9)	(−7)	−24	−27	−29	−34	−34	−29	−14	9	24	−11.3	58
Precip.	No data													

315. Precipitation. If little is known about the temperatures of the ice-cap climates, still less is known concerning their precipitation. There is no doubt that it is meager, and probably all of it falls as snow, most of it in the form of dry, hard, sandlike particles which are readily driven before the wind. The origin of the precipitation over the ice caps is not well understood. In such regions, although melting is practically absent, there is some loss by evaporation as well as through glaciers moving out to the sea. Enough precipitation must be accounted for to offset these losses. No doubt a portion of the inland snow has its origin in the cyclonic storms that pass along the margins of the ice plateaus. It may, in part, result from condensation in the form of fine ice particles or as hoarfrost within the descending air of the polar anticyclones as it reaches the intensely cold ice surface. The rate of deposit is exceedingly slow, no doubt, but since it is seasonally continuous, the total amount may be considerable.

12. Highland Climates (*H*)

316. Altitude and Exposure as Climatic Controls. Next to the distribution of land and water, elevation above sea level is the most important control causing differences in climate in similar latitudes. The climatic effects of such elevated land masses as mountains and plateaus are expressed through the two factors (*a*) *altitude* and (*b*) *exposure.*

It needs to be emphasized, however, that there is no such thing as a *highland type of climate* in the same sense that there is a savanna or a Mediterranean type. Almost endless varieties of local climates exist within a mountain mass, the atmospheric conditions varying markedly with altitude and exposure and of course with latitude as well. The enclosed valley or plateau is very different climatically from the exposed peak; windward slopes contrast markedly with those having leeward positions, while flanks inclined toward the sun are dissimilar to those oppositely inclined. And each of these in turn is different at various *altitudes* and *latitudes.* Above an elevation of 5,000 or 6,000 ft. marked differences in temperature are conspicuous between sunshine and shade, wind and calm. Representative temperature and rainfall curves for highland climates scarcely can be said to exist, and only the most flexible generalizations are broadly applicable. On Plate III, which emphasizes a relatively small number of simple types of climate, no attempt has been made to show the

varieties of climate within great mountain masses. Instead most of the *high* mountain and plateau areas in low and middle latitudes have been included within one general group, *highland climates*. In contrast, regions of *moderate* elevation and relief, especially where there is considerable land utilization, have been included within the general climatic type characteristic of the surrounding lower lands, even though they may represent a modified form of the lowland climate. Up to an altitude of about 4,000 or 5,000 ft. the peculiarities of altitude climate are not prominent, but above 6,000 ft. they are usually very noticeable (*cf.* Plates III and V).

317. Atmospheric Pressure in Mountains. At low elevations the minor changes in air pressure from day to day, or from season to season, are directly imperceptible to the human body. However, the very rapid decrease in the atmosphere's weight with increasing elevation and the very low pressures that prevail in high mountains and plateaus cause this element to be a genuinely important one in highland climates. At an elevation above sea level of about 17,500 ft., pressure is reduced to approximately one-half its sea-level value. The highest human habitations are found below this level, although there are said to be settlements in Tibet and the Bolivian Andes the elevations of which approach it. Physiological effects (faintness, headache, nosebleed, nausea, weakness) of decreased pressure aloft are experienced by most people at altitudes above 12,000 to 15,000 ft. Sleeplessness is common, and exertion is difficult. Usually mountain sickness is a temporary inconvenience that passes away after a week or so of residence at high altitudes. Some persons, however, never become acclimated to the reduced pressure.

TEMPERATURE AND INSOLATION

318. Insolation. Intensity of sunlight increases aloft in the cleaner, drier, thinner air of mountains. This is to be expected, since dust, moisture, and other principal scattering and absorbing elements of solar radiation in the atmosphere are much more abundant at lower elevations. On a clear day probably three-fourths of the insolation penetrates to 6,000 ft., but only one-half to sea level. The great relative intensity of the sun's rays attracts the attention of nearly all persons going to high elevations. This intensity of insolation causes soil temperatures to be relatively high as compared with the cooler air temperatures.

Insolation not only is more intense in the higher altitudes, but it also is proportionally richer in the shorter wave lengths of energy, or the violet and ultraviolet rays. One therefore burns and tans quickly in mountain sunlight. The greater therapeutic quality of this short-wave radiation is one reason for establishing many sanatoriums in the higher altitudes.

319. Air Temperature. Probably of most fundamental importance among the climatic changes resulting from increased elevation is the decrease in air temperature (about 3.3° per 1,000 ft.), and this in spite of the increased intensity of insolation. Quito, Ecuador, on the equator, at an elevation of 9,350 ft. has an average annual temperature of 55°, which is 25° lower than that of the adjacent Amazon Lowland. But although the clear, rare air at that elevation, which is incapable of absorbing and retaining much energy, remains chilly, the sun is intensely strong. It is a climate of *cool shade and hot sun*. Viscount Bryce has the following to say concerning his experience on the Bolivian plateau: "The keen air which this elevation gives has a fine bracing quality, yet there are disadvantages. One is never warm except when actually in the sunlight. . . . The inhabitants get accustomed to these conditions and shiver in their ponchos, but the traveler is rather wretched after sunset and feels how natural was Sun worship in such a country."

Climatic Data for a Highland Station in the Tropics
Quito, Ecuador (9,350 Ft.)

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	54.5	55.0	54.5	54.5	54.7	55.0	54.9	54.9	55.0	54.7	54.3	54.7	54.7	0.7
Precip.	3.2	3.9	4.8	7.0	4.6	1.5	1.1	2.2	2.6	3.9	4.0	3.6	42.3	

Vertical temperature gradients along mountain slopes are many times steeper than the most severe winter horizontal gradients on lowlands. In the low latitudes, by a railroad trip of only a few hours, one can be transported from tropical to polar climates. This fact of steep vertical temperature gradients in mountains is particularly significant in the low latitudes, where, as a result of the prevailingly high temperatures of the lowlands, people look with favor upon elevated regions where they are able to escape the oppressive heat. Largely because of their lower temperatures, elevations in the tropics commonly become the centers of concentration for white population. In tropical Latin America, for instance, the capital cities of Venezuela, Colombia, Bolivia, and five of the Central American republics are on highlands. In India, the so-called "hill stations" of the sub-Himalayas, such as Darjeeling, Simla, Murree, and Naini Tal, at elevations of 6,500 to 7,500 ft., become havens for white residents from the lowlands during the long, hot season.

320. *Temperature Zones on Tropical Highlands.* As a consequence of the steep temperature gradients that characterize mountains, several zones of climate, with characteristic vegetation covers and crops, may be recognized. In the mountainous parts of tropical Latin America, four such zones commonly are delimited, *viz.*, the *tierra caliente* (hot lands), *tierra templada* (temperate lands), *tierra fría* (cool lands), and the cold *paramos*, or *puna* (Fig. 130). Quite naturally these altitudinal belts are not defined by identical elevations throughout the entire tropics. In general the bounding elevations become lower with increasing distance from the equator. The lowest zone, or *caliente*, normally extends from sea level to 2,000 to 3,000 ft. (annual temperature roughly 83 to 75°). Where precipitation is abundant it is characterized by a luxuriant vegetation cover of trees or of trees and tall grass and by such crops as rubber, bananas, and cacao. The *tierra templada* lies above the *caliente* and extends up to 6,000 or 6,500 ft. (temperature roughly 75 to 65°). Within this climatic belt is produced a great variety of crops, among them coffee, maize, tea, cotton, and rice. *Tierra fría*, lying above the *templada*, prevails up to 10,000 to 11,500 ft. (temperature 65 to 54°). There middle-latitude crops such as wheat, barley, apples, and potatoes are at home, and the pastoral industries frequently are well developed. At still higher elevations are the cool or

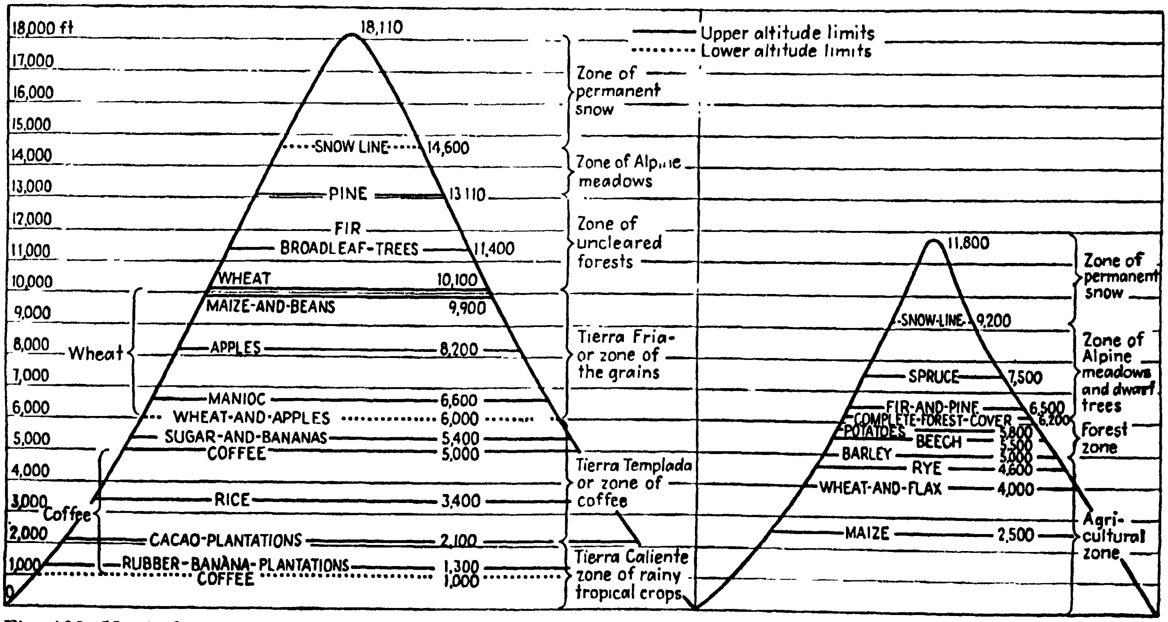

Fig. 130. Vertical temperature zones and altitude limits on a tropical (left) and middle-latitude mountain (right). (*After Sapper.*)

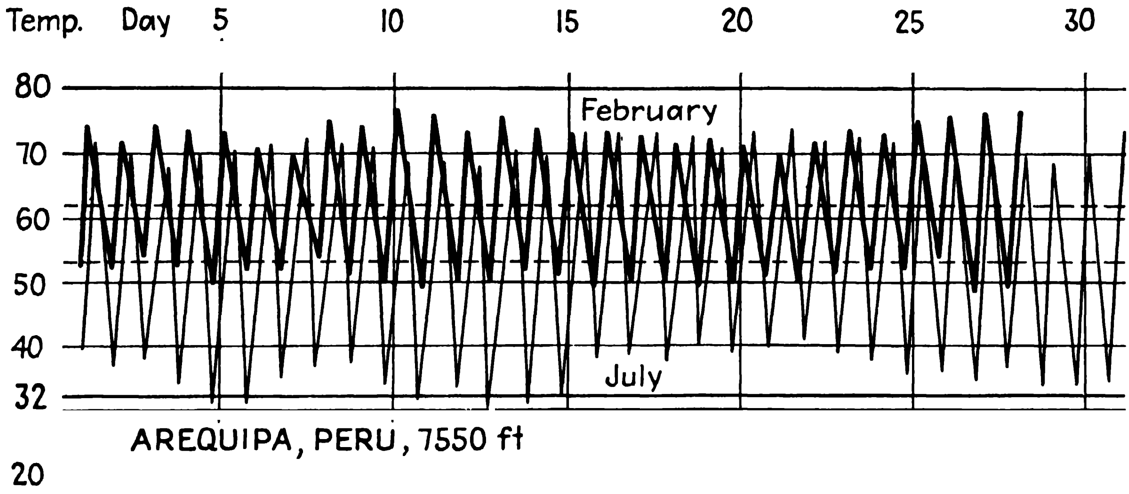

Fig. 131. A mountain station in the tropics.

cold paramos, in which the raising of crops is relatively unimportant, although grazing may still persist. Trees are not uncommon in lower parts of the paramos, but its higher elevations are the zone of alpine meadows. Above heights of 14,000 to 15,000 ft. the zone of perpetual snow is usually encountered. Local trade of considerable importance, fostered by this temperature zonation of products, is carried on between the inhabitants at various altitudes.

321. *Seasonal Temperatures.* The lower temperatures at elevated sites have led to the statement that mountains in the tropics enjoy perpetual spring. Quito's annual temperature of 54.7°, for instance, is not greatly unlike the May average at Madison, Wis. However, the great variety of elevations within a tropical mountain mass obviously results in all gradations of temperature.

But although the thermometer stands lower on a tropical mountain than it does on an adjacent lowland, both locations have a similar *uniformity* in monthly and daily temperatures. Small seasonal ranges, and the same monotonous repetition of daily weather, belong alike to tropical highlands and plains (Fig. 131). At Quito, for instance, the temperature difference between the warmest and coolest months is only 0.7°, which is even smaller than that of the Amazon Lowlands in the same latitude. Mexico City at 7,474 ft. has an *average annual temperature* 17° below that for Veracruz on the coast, yet their *annual ranges* are almost identical—11.5 and 11°, respectively. One climatologist has stated the situation tersely by saying: "The pitch changes; the tune remains the same."

322. *Middle-latitude Highlands.* While within the tropics mountains and plateaus may be climatically desirable because of their lower temperatures, this same characteristic causes highlands in the middle latitudes to be climatically inferior to lowlands. The difference lies in the fact that tropical lowlands have an *excess* of heat, so that any reduction of temperature with altitude usually is counted as an advantage, for human comfort as well as for the greater variety of products than can be grown. In the middle latitudes, on the other hand, even the lowlands usually are none too warm, so that reduction of temperature with altitude, causing a cooler summer and shorter growing season, materially decreases the opportunities for agricultural production. In other words, there are fewer *utilizable* temperature zones in middle-latitude highlands.

Climatic Data for a Representative Altitude Station in Middle Latitudes

Longs Peak, Colo. (8,956 Ft.)

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	23	22	26	33	41	51	55	55	48	39	31	24	37	33
Precip.	0.7	1.2	2.0	2.7	2.4	1.6	3.6	2.2	1.7	1.7	0.9	0.9	21.6	

PRECIPITATION

323. Increased Precipitation in Mountains. Precipitation is characteristically heavier in highlands than it is on surrounding lowlands. Thus on a rainfall map mountains are conspicuous as "islands" of heavier precipitation. This fact is admirably illustrated by the Pacific Coast mountains in the United States, by the Abyssinian Highlands in northeastern Africa, and by the Himalayas in southern Asia. The lack of weather stations in many mountain areas of the world, and the consequent dearth of rainfall data for numerous highlands, is a reason why many more such areas do not stand out conspicuously on precipitation maps. The reasons for the increased precipitation in highlands has been discussed in an earlier section of this book. Whether or not rainfall continues to increase with increasing elevation, up to the tops of high mountains, or whether there is a zone of maximum precipitation above which the total amount declines, is not known for sure.

It is especially in dry climates, no matter in what latitude, that the heavier rainfall of highlands is of such critical importance. In regions of drought, mountains, besides being "islands" of heavier precipitation, are islands of heavier vegetation cover and more abundant agricultural production as well. In both arid and semiarid lands, highlands are likely to bear a cover of forest in contrast to the meager grass and shrub vegetation of the surrounding drier lowlands. The Black Hills of western South Dakota are "black" because their dark-green forests present such a color contrast with the tawny-hued steppes surrounding them. Not only are settlements attracted to the humid slopes and to the well-watered mountain valleys, but streams, descending from the rainier highlands, carry the influence of highland climate far out on the dry lowlands. Thus the Yemen Highlands in southern Arabia, and the adjacent lowlands watered by its rivers, are a garden spot and the principal center of settlement in that otherwise largely desert country. In eastern North Africa the Abyssinian Highlands are a similar "culture island" while the Nile floods have their origin in this same mountain knot. The waters of the Colorado River, with its principal sources in the Rocky Mountains, make possible the agricultural utilization of the dry Imperial Valley of southern California, over 700 miles distant. From the Andes come the 50 or more small streams that, crossing the Peruvian Desert, nourish the parallel irrigated strips of that otherwise waste land.

WINDS

324. On exposed mountain slopes and summits, where ground friction is small, winds are usually strong. Mountain valleys, on the other hand, are particularly well protected against violent winds. Owing to the great variety of relief and exposure in highlands, there are also a number of local winds characteristic of such areas. The diurnal reversal of wind direction, upslope by day and downslope by night, has been discussed previously under the head of *mountain and valley winds.*

325. *Foehn*, or *Chinook.* Still another local vertical wind, characteristic of mountains, is the cyclonic-induced *foehn*, which in the United States and Canada is known as the *chinook*. It is a relatively warm, dry wind which descends a mountain front when a cyclonic storm causes air to cross the range from the opposite side of the divide (Fig. 132). For example, as a well-developed low travels southeastward down the Great Plains, paralleling the Rocky Mountain front, air is induced to ascend over the Rockies from the western side and descend their eastern slopes. The relatively high temperature and aridity of the chinook originate as follows: As the air ascends on the western side of the Rockies, condensation occurs, so that the rising air reaches the top of the divide with much of its moisture gone *but still retaining a relatively high temperature* as a result of liberation of heat of condensation during ascent. As this air descends on the side of the mountain toward the cyclone, it is further heated by compression and made relatively drier, so that it arrives at the eastern base of the Rockies as a mild, arid wind. The warmth of the chinook, therefore, is of dual origin: (*a*) heat of condensation and (*b*) heat resulting from compression. Usually its temperature is not over 40° in winter, but this appears very warm, by contrast at least, after a

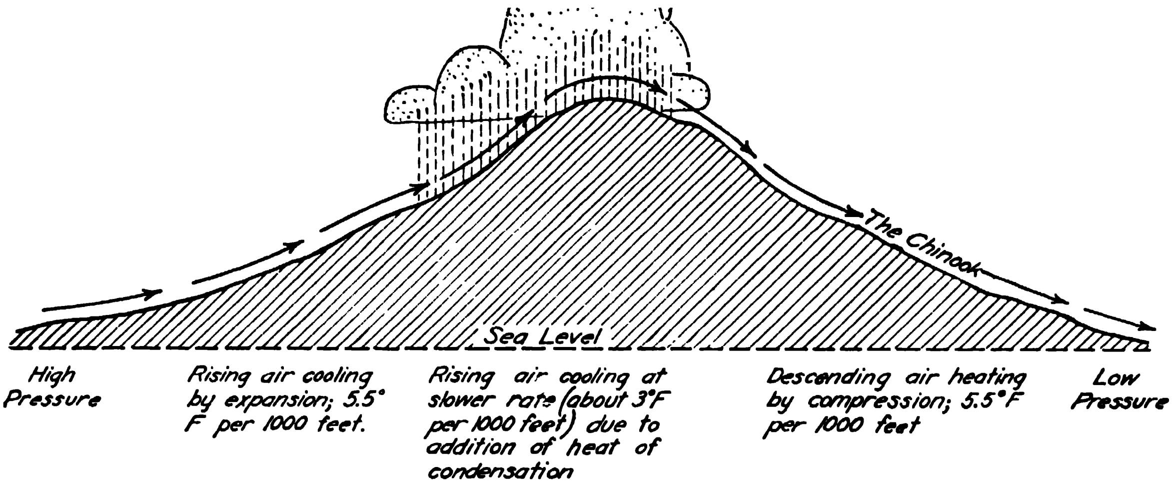

Fig. 132. Diagrammatic representation of foehn, or chinook, winds.

period of anticyclonic weather with intense cold. If snow lies on the ground, it vanishes as if by magic before the warm blast of the chinook. A rise in temperature of 40° within 24 hr. is not unusual. At Kipp, Mont., there is the extraordinary record of a 34° rise within an interval of 7 min. The genuine chinook country is the High Plains at the eastern foot of the Rockies from southern Colorado northward to the limits of settlement in Canada. The milder winters of this western portion of the plains, as compared with regions farther east, are associated with the prevalence of these local mountain winds. Here the snow cover is less persistent, so that grazing can go on throughout the winter. Foehn winds are by no means confined to the eastern Rocky Mountain foothill country but, on the contrary, are found in almost all mountain areas where cyclonic storms are prevalent. No doubt the region where they are best known is the Swiss valleys on the northern side of the Alps.

DAILY WEATHER

326. In highlands the weather changes within the 24-hr. period are likely to be greater than they are on adjacent lowlands. Violent changes from hot sun to cool shade, from chill wind to calm; at one period gusts of rain or possibly snow, and then again intense sunlight—such is the erratic nature of the daily weather. Even within the tropics, the complex sequence of daily weather stands out in marked contrast to the uniformity of temperature conditions between the months.

> The night and early mornings are cold and raw, but the powerful sunshine raises the temperature rapidly, and by noon it feels hot in the sun, though in the shade it is still cool. About midday clouds gather and there is often a violent thunderstorm in the afternoon with heavy rain, hail, and frequently snow. These clouds and storms are essentially convectional, and they die away after the heat of the day which caused them. . . . The early mornings are fine, and the air at these great altitudes (Quito, Ecuador) is remarkably clear; but in the afternoons the clouds hang low over the gloomy landscape, and hail, snow, and rain chill the air, so that the mountains are almost invariably hidden.[1]

[1] Kendrew, "The Climates of the Continents," 3d ed. P. 320. Oxford University Press, New York, 1942.

SECTION C: *Processes Concerned with the Origin of Landforms*

327. The earth upon which man lives is characterized by great and often pleasing variety in its surface features. High lands and low, level expanses and steep slopes, plains, plateaus, hill lands, and mountains are arranged in endless combinations which furnish the stage upon which the play of human life is enacted. Because there are so many kinds of landforms, it may sometimes seem that they are distributed over the earth without order and that an understanding of their nature and arrangement is beyond the ability of the beginning student. Such is not the case. It is quite as possible to understand the meaning of earth features and to perceive them in their interrelationships as it is to reach an understanding of the major climatic types of the world.

The study of climates in the preceding chapters was approached through a consideration of the elements and processes of the atmosphere. In the same manner, the study of landforms may be approached through a brief survey of the materials of which they are composed and the processes by which they originate. Although the student of geography is interested primarily in the shapes and patterns of the surface features of the land and in their human utility as elements of the regional equipment, a clear understanding of them is best reached through at least a brief survey of the *substances* of which they are made, of the *agents* that are involved in their origin, and of the *processes* by which they originate or by which their shaping is accomplished. It is the object of Sec. C (Chaps. 12 and 13) of this book to furnish that brief survey, reserving for Sec. D the details of interpretative description relating to the appearance of landforms produced by the work of the various agents.

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CHAPTER 12: *Earth Materials and the Tectonic Processes*

Earth Materials

328. Important Earth Elements. The earth's crust (lithosphere) is composed mainly of rocks. Rocks are aggregations of minerals, and minerals are chemical elements or combinations of them. All but a few of the 96 known chemical elements exist in the earth, but many of them are extremely rare. Some others are more common but still do not make up a great part of the lithosphere. Of them all only eight are abundant.

Oxygen is the most abundant of these. In an array of combinations with other elements it comprises nearly 47 per cent of the known crust of the earth. *Silicon* is next most abundant, for it combines with other elements so commonly that it makes up nearly 28 per cent of the total mass. Six other elements together make up 24 per cent of the total. They are, in the order of their abundance, *aluminum*, *iron*, *calcium*, *sodium*, *potassium*, and *magnesium*. The remaining 2 per cent of the earth's crust includes a long list of elements some of which, though small in amount, are of critical importance in human affairs. In this group are such as radium, platinum, gold, silver, and various of the semiprecious minerals.

329. Minerals are sometimes composed of single chemical elements, such as pure copper or gold. More commonly they are combinations of two or more elements in chemical unioı A mineral may be defined as a natural inorganic[1] substance having a nearly constant chemical composition and fairly definite physical characteristics. The latter usually include a distinctive crystalline form. In such minerals the elements are united in molecules which are very different from any of the constituent elements. Thus iron, a metallic element, may unite with oxygen, a gas, and water, a liquid, to form a soft brown earthy mineral, limonite, which is familiar as iron rust. The list of known minerals is a long one containing many hundreds of names, but, as in the case of the elements, a few of the many are so much more common than the others that they make up the bulk of the lithosphere. Of these, *quartz*, a hard glassy mineral which is a combination of silicon and oxygen, is most important. It is the substance of common sand. Also important are the *feldspars*, a group of light-colored minerals including combinations of silica, aluminum, and oxygen with various other elements such as sodium, calcium, or potassium. The decomposed fragments of the feldspars, together with some fine sands and other substances, make up the bulk of ordinary clays. A third group is the *ferromagnesian minerals*, dark heavy combinations of silica with iron, magnesium, and other elements. Some minerals include several chemical elements in extremely complicated combinations.

330. Rocks. Minerals, singly or in association, make up the rocks of the earth's crust. In rocks the component minerals exist separately and not in chemical combination. Moreover, the component minerals in various specimens of the same class of rock are not necessarily identical in kind or amount. They are locked together in an almost infinite array of physical combina-

[1] Coal and petroleum are derived from materials which were originally organic, but they have been so changed during a great lapse of time that they are now considered to belong to the mineral kingdom. They are always spoken of as "the mineral fuels," but they do not have all the characteristics of the rock minerals.

tions the patterns of which depend upon various things, especially the nature and proportions of the component minerals, their peculiarities of crystalline structure, and the history of the rock since its origin. It is clear that, since there are hundreds of minerals that may be combined in a great variety of ways and proportions and then subsequently changed by events in the history of the rock, the total number of different kinds of rock is very large. The many kinds can be grouped, according to their origin, into three general classes: (*a*) igneous, (*b*) sedimentary, and (*c*) metamorphic rocks.

331. Igneous rocks are those which have been solidified from a molten state (Fig. 134). Even though they all are alike in that respect, they still are of great variety and may be grouped in different ways, such as (*a*) extrusive or intrusive, (*b*) coarsely or finely crystalline, and (*c*) acid or basic, according to the chemical nature of their predominant minerals. Although there are some notable exceptions to the rule, it is generally true that the igneous rocks are compact, of low porosity, and resistant to erosion as compared with those of sedimentary origin.

332. *Classes of Igneous Rocks.* Extrusive rocks are solidified from molten materials poured out upon the earth's surface. Such are the products of a volcano of which lava, pumice, and finely divided rock particles called ash are examples. Some molten rocks, however, are pushed from within the earth toward the surface but, never reaching it, are left to cool slowly deep underground. These are called *intrusive*, although later they may be widely exposed by the removal of the covering layers. Granite is a rock of that class.

Extrusive rocks ordinarily are cooled quickly, giving little time for the collection of molecules of similar sorts into crystals of appreciable size. Such are, therefore, finely crystalline, or they may have no crystals at all and are then classed as volcanic glass. Intrusive rocks, when introduced in giant masses well below the surface, may have their cooling and solidification delayed for thousands of years. During that time minerals of like nature come together in the liquid and build up a coarse, interlocking crystalline structure.

Igneous rocks are called *acidic rocks* if their minerals are predominantly feldspar and quartz, and if they are light in color and have only minor amounts of the ferromagnesian minerals. Granite is such a rock, and commonly it has crystals so coarse as to be plainly visible. Others, in which the principal minerals are of the dark, heavy ferromagnesian groups, and in which quartz is minor or absent, are said to be *basic rocks*. Gabbro and basalt are examples of basic rocks.

The significance to the student of geography of these major distinctions between classes of igneous rocks lies in the differences in landforms produced by and developed in them, in the qualities they impart to some soils derived from them, in their relation to the origin of mineral ores, and in their comparative qualities for structural and other human uses. For example, the acidic rocks, being high in quartz, do not readily decompose and are therefore good structural materials, and they also are likely to resist erosion and form conspicuous relief features. The ferromagnesian minerals, on the contrary, decompose more readily, and rocks composed of them are not commonly used in building. Neither are they so commonly the cause of prominent surface features.

333. Sedimentary rocks are principally such as have been deposited as sediments. Their components have been derived, directly or indirectly, from the disintegration of older or primary igneous rocks: sand from the quartz grains, clay and lime from the decomposed feldspars and other minerals. Some are the deposits of wind and streams on the land, but more largely they are put down in bodies of water such as lakes or, especially, the sea. They may be derived from materials that are rolled about by waves, like sand or gravel; or, like clay, are suspended in the water; or, like lime, are carried in dissolved form. Usually the sediments are deposited somewhat according to their size or weight and therefore accumulate in beds of similar nature which cover considerable areas. The process of deposition of most sedi-

Fig. 133. Stratified rock. An exposure of thin-bedded sedimentary rock grading upward into regolith and soil. (*Wisconsin Geologi… …cy photograph.*)

mentary rocks appears not to have been perfectly continuous for lengths of time sufficient for the building of great thicknesses but to have been interrupted. The interruptions are marked by changes, often slight, in the kind or quality of deposit which results in the formation of distinct layers, or *strata*, which are separated by planes of weakness called bedding planes (Fig. 133). Hardened sediments often are called *stratified rock*. The principal place of deposition for sediments is the nearly level floor of the shallow seas near present or former shorelines. The normal attitude of most sedimentary strata is, therefore, practically horizontal, and when such rocks are found in positions greatly inclined from horizontal it is an indication that there has been a disturbance of the materials after their deposition. The processes by which ocean-bottom sediments become elevated to form part of the continental surface are reserved for future consideration. Here it may be noted merely that such is the fact and that the soft ocean sediments become consolidated into rock by compression, resulting from the great weight of the overlying accumulations, or by the cementing action of infiltering chemical materials. The principal classes of sedimentary rocks are (*a*) sandstone, (*b*) shale, and (*c*) limestone. However, the distinction between them is not always sharp since the materials often were intermingled as sediments or are graded from sands into muds or from muds into limy deposits, with increase in distance from the shoreline. Thus, there are sandy or shaly limestones, limy sandstones, etc. The classes of sedimentary rock differ considerably in their relations to landforms, soil origin, and other aspects *of regional character*.

334. *Sandstone* is comprised mainly of sand, coarse or fine, most of which was washed by the waves of ancient seas and deposited in shallow waters along their shores. The hardening of the sands into rock is accomplished by infiltered clay or lime, or sometimes silica or iron oxide, deposited from solution. These act as cements, attaching the sand grains together, in some instances firmly, in others poorly. Some sandstones are well cemented and are in comparatively thick beds (massive sandstone), while others are so poorly cemented or so thinly bedded that they disintegrate readily upon exposure. Because of their composition, most sandstones are comparatively porous and per-

meable to water, but the silica of which they are composed is relatively insoluble. Therefore, massive sandstones often stand in cliffs or ridges while less resistant rocks are wasted away.

Closely allied to the sandstones are rocks called *conglomerate*. These are composed of coarse gravels, pebbles, or boulders which are imbedded in, and held together by, a ground mass usually of sandstone, much after the manner of man-made concrete.

335. *Shale* is consolidated mud (clay or silt). Some shales consist of minute grains of clay and occur in relatively massive layers. Others are comprised largely of microscopic flakelike fragments of mica and other minerals. These latter have settled in quiet water with their flat surfaces roughly horizontal, and they form paper-thin layers along which the shale rock separates readily into chips upon weathering. The deposit may contain lime that acts as a cement, or it may be hardened as a result of compression by the great weight of overlying rocks. Usually, shale is a relatively nonresistant rock which disintegrates easily upon exposure at the surface, and because it yields readily to the attacks of the elements it often gives rise to lowlands and to clay soils. However, it is comprised of fine grains and has small pore spaces. It is, therefore, a compact insoluble rock and does not readily permit the movement of water underground.

336. *Limestone* is a rock produced by the compacting of limy sediments, derived from chemical precipitates of lime in sea water or from the fragments of shells. In some places are found thick deposits of nearly pure limestone (calcium carbonate). More commonly they contain admixtures of other materials, especially sand or clay. Bodies of dense siliceous material also are found in limestones and are recognized as bands or masses of *chert*, or *flint*. Some limestones are compact and hard, others soft and porous. The latter are called chalk and are exemplified in the ranges of hills in southern England and the famous chalk cliffs of Dover. Some limestones are ridge makers, whereas others give rise to lowlands. The different classes of features to which they give rise depend largely upon differences in climate and in the composition of the limestones concerned. Unlike most rocks, pure limestones are readily soluble in ground water and through long-continued solution sometimes develop interior cavities or even great caverns, such as the Mammoth Cave of Kentucky. It is because of their solubility that limestones in regions of humid climate commonly, but not always, give rise to lowlands, while those in regions of dry climates commonly stand out as features of striking relief. A closely related rock, called *dolomite*, which is calcium magnesium carbonate, is much less soluble than limestone and commonly is a ridge maker, even in regions of humid climate (405).

337. *Less Abundant Sediments.* Not all sediments are of marine origin. Some appear to have been deposited in shallow coastal bays or marshes. Among these are organic deposits such as coal, iron-bearing sediments such as bog iron ore (limonite), and other forms of iron deposits. Some clearly have been deposited by streams or the wind, and still others are rocks believed to have resulted from deposits in the evaporating waters of interior basins or coastal lagoons in arid climates. Such are rock salt and gypsum.

338. Metamorphic rocks are derived from rocks of any other kind by processes of change. The commonest causes of change are pressure, heat, and the cementing action of percolating waters underground. In some metamorphic rocks the change appears to have been produced in a relatively short time (geologically speaking) by means of the great pressures exerted in the warping and bending of rocks in the progress of mountain building or by the great heat resulting from the introduction of molten lavas into older rocks or by both at once. Other rocks appear to have been changed by the extremely slow processes carried on through the alteration or replacement of minerals by underground waters.

Metamorphism in some rocks has involved a change so great as to produce minerals not present in the parent rock. Some of the valuable mineral ores are formed in that way. In others the changes are mainly those of form produced

by recementation, by recrystallization, or by rearrangement of the crystals.

339. *Common Metamorphic Rocks.* Metamorphism affects both igneous and sedimentary rocks and so generally that nearly every common rock has a well-known metamorphic equivalent. Granite, for example, may be metamorphosed into a *gneiss* or *schist*. A sandstone metamorphosed becomes a *quartzite*, a rock of extreme hardness and resistance to erosion. A shale subjected to great pressure has its particles further flattened and arranged in more perfect parallelism so that the rock readily splits or cleaves. It is called *slate*, a rock of considerable economic value. A pure limestone, under similar processes, becomes recrystallized, sometimes takes on a translucent or waxy appearance, and is called *marble*. Bituminous coal becomes anthracite when metamorphosed or, if the process is carried far enough, *graphite*, the substance used in pencil leads.

In several parts of the earth are vast areas of rocks of great age and complexity. Some, doubtless, originally were igneous, others sedimentary. Whatever their original nature, they have been subjected, during the long progress of geological time, to deformative processes. In some regions these processes have been repeated on a vast scale more than once. As a result the rocks of these regions generally are metamorphosed to a high degree and have been largely recrystallized. Regions of that kind are sometimes broadly characterized as "areas of ancient crystalline rocks" (Fig. 198).

340. Rock and Mantle Rock. Over most of the land surface of the earth the solid rock of the earth's crust is buried underneath a covering layer, thin or thick, of disintegrated and decomposed rock fragments. This material is named *regolith* but is sometimes called mantle rock (Fig. 133). Not everywhere is the regolith sufficiently thick to cover the underlying rock. On steep slopes almost everywhere, and in some regions over large areas generally, the bare and solid rock may be seen. These exposures are briefly described as *outcrops*. Through the nature and attitude of the rocks displayed in widely scattered outcrops geologists are able to form intelligent opinions as to the kind, distribution, and extent of the rocks buried underneath the regolith.

341. Lithic Regions. The rocks that underlie a region are associated in many significant ways with other of its natural and cultural features. For example, there is in some places a close relationship between the underlying rocks and the soil, since the regolith is the parent material of the soil and in some places is the principal constituent of the soil itself. The nature and structure of rocks often are reflected in the details of relief features and in the kinds and distribution of mineral resources. In many regions the rocks are of such different kinds, and change from one kind to another within such short distances, that they may be described only as regions of complex rocks. However, there are certain large regions in each of which a single class of rocks, such as recent sediments, older and more altered sediments, igneous rocks, or ancient crystalline rocks, is so widespread that it imparts at least some degree of fundamental unity to the region in which it is dominant. The larger of the world regions of rock similarity are worthy of consideration in connection with matters to be noted later. They are shown in Plate IV, which is entitled "Lithic Regions."

From that map it will be seen that, although sedimentary rocks are included in some of the world's regions of mountainous relief, still larger expanses of them are found in the great interior plains and coastal plains of the several continents (Classes 2 and 3, Plate IV). In total, they underly the larger part of the land surface of the earth. It will be noted also that there are several large areas of ancient crystalline rocks (Class 1, Plate IV). They are found especially in the regions surrounding Hudson Bay in North America, Scandinavia and Finland, Central Asia, eastern and northern Brazil, eastern Africa, and western Australia. There are other areas of similar rocks too small to be shown on that map. It will be seen also that there are only a few large areas in which igneous rocks are dominant (Class 4), although many small ones

are included in the mixed rocks which are characteristic of most of the mountainous regions of the world (Class 5).

THE SURFACE-MOLDING FORCES

342. The Origin of Landforms. The major subdivisions of the earth's relief features are the great depressions which contain the oceans and the broad elevations which are the continental platforms. Upon the bottoms of the ocean depressions there are features of a smaller order of size about which comparatively little is known because they are covered by water. Upon the tops of the continental platforms also are other features of a smaller order of size about which a great deal is known and with which people have daily and intimate concern. They are the high mountain masses, broad plateaus, rough hill regions, and extended plains. Of a still smaller order of magnitude are the local features, hill or gully, dale or plain, which are a part of the immediate environment of every community.

Landforms, whether large or small, result from the interaction of certain forces with the materials of the earth's surface through longer or shorter periods of time. Some of the forces may be described as geologic, some as climatic, and still others as biologic. They accomplish their various kinds of work by means of *processes* of whose operation at least the rudiments must be understood. The forces work by means of these processes upon an earth crust made up of rocks of different kinds and degrees of resistance, arranged in different positions and attitudes with respect to each other and the surface of the earth.

343. The Time Element in Physical Geography. The student of landforms and the processes by means of which they have evolved must adopt a different conception of time from that employed in considering the events of human history. Although some of the processes of nature are sudden and violent, accomplishing notable results in a short space of time, such are the exception rather than the rule. Most of the common landforms have been produced by the slow and long-continued operation of forces and processes still at work. Explanation of the fact that they are able to produce so little effect within a lifetime or within the span of human history requires merely the use of a different time scale for their measurement.

It is estimated by geologists that the age of the earth probably exceeds 1½ billions of years. Of this vast span of time the record of the first two-thirds is vague and partly lost in antiquity. It is like that long period in human development before man learned how to make any written record of his doings. More is known of the latest one-third of earth history (around 500 million years). But even that time is so long that it dwarfs human history to a moment by comparison. However, most of the present landforms of the earth trace their origins to events in that time and especially in the later or more recent periods of that time. It is not desirable to enter here upon a study of the periods of time into which geologic history is divided, although it may be convenient in some connections to make references to them. As a basis of reference, and to provide a better conception of the time element in the evolution of landforms, as well as for its general interest, a simplified form of the geological column is reproduced in Appendix E. This tabular arrangement of the periods of earth history in major outline shows also some of the principal events in the biologic sequence which geological science has interpreted from the records of the rocks.

344. The Forces Involved in Surface Molding. The various forces involved in the production and alteration of landforms may be grouped for convenient study in more than one way to suit different objectives. For the present purpose it will be helpful to think of them as belonging to two major groups: (*a*) those forces which originate *within* the earth and (*b*) those which originate from *without*, or beyond, the earth.

The members of the first group derive their energy mainly from changes occurring in the earth's interior, changes such as heating through radioactivity or chemical recombination, expansion or contraction, or the removal of liquid material from one place to another. This

group may be called the *tectonic forces.* They are made manifest through processes called *diastrophism* and *vulcanism.* Diastrophism includes those processes which are involved in the breaking, bending, and warping of the earth's crust and the elevation, depression, or displacement of one part with respect to another. Vulcanism includes those processes which involve the transfer of molten material from one place to another within the earth's crust or its expulsion at the earth's surface. *The tendency of the tectonic forces and their processes is to cause differences in surface elevation on the earth* and, by heaving up the crust here and depressing it there or by pouring out upon it great masses of molten lava, to construct surface features of great height and areal extent.

The members of the second group derive their energy mainly from the sun. They may be called the *forces of gradation.* They operate largely through the work of agents such as wind, running water, moving snow and ice, and living organisms. *The tendency of the forces of gradation and their processes is to bring the surface of the land to a uniform low slope or grade.* This is done by tearing down all elevations, such as may be produced by the tectonic forces, and by filling up depressions. The processes of gradation are of two types. These may be called *degradation* and *aggradation.* Under degradation may be included all the processes by which lands that stand higher than the level of the final slope, or grade, are brought down to it. Conversely, under aggradation may be included all the processes that tend to fill the sea margins, tectonic basins, and other depressions with sediment and thus bring them up to grade. The process of degradation itself may be thought of as consisting of three steps: (*a*) the preparation of rock material for removal, (*b*) the picking up of the rock fragments, and (*c*) their transportation. The process of aggradation consists of the deposition of the fragments.

The force of gravity operates in conjunction with both the tectonic and gradational groups. It doubtless is intimately concerned with the contraction of the earth and, hence, with various disastrophic and volcanic consequences arising therefrom. It is concerned also with the work of the wind, of running water, and of moving glacial ice. Solar energy, to be sure, indirectly causes differences in atmospheric pressure and the evaporation of the moisture which descends upon the land as rain or snow. But it is gravity that causes winds to blow and streams and glaciers to flow and do gradational work.

The two groups of forces, *tectonic* on the one hand and *gradational* on the other, are at work continuously and, therefore, are in endless conflict. The one causes features having differences in elevation; the other tends to reduce them to a low and uniform plain. The hills, valleys, and other relief features that now exist show the present, but temporary, state of this perpetual battle.

The Tectonic Processes

DIASTROPHISM

345. It is well known that any rock, under sufficient stress, will break or bend. Stresses sufficient to distort even the massive rocks of the earth's crust are believed to originate in several possible ways, such as (*a*) the slow movement of plastic material from one place to another underneath the earth's crust, (*b*) the redistribution of surface load caused by the removal of material from one part of the surface and its deposition elsewhere, or (*c*) the expansion or shrinkage of the earth as a whole.

346. Crustal Fracture. Stresses sufficient to cause crustal fracture have developed so many times that the solid rock is nearly everywhere traversed by cracks called *joints.* These are so numerous near the surface that the hard exterior of the earth must resemble the crackled glaze on a piece of antique china (Fig. 134). However, the joints become smaller and fewer with depth and below a dozen miles or so are believed not to exist. This cracked surface zone is called the *zone of fracture.* The joints permit the water of the ground to circulate more freely within the rocks and enable the agents of gradation to work more readily. In some places also they play a part in the details of shape in landforms.

Under severe stresses rocks not only break

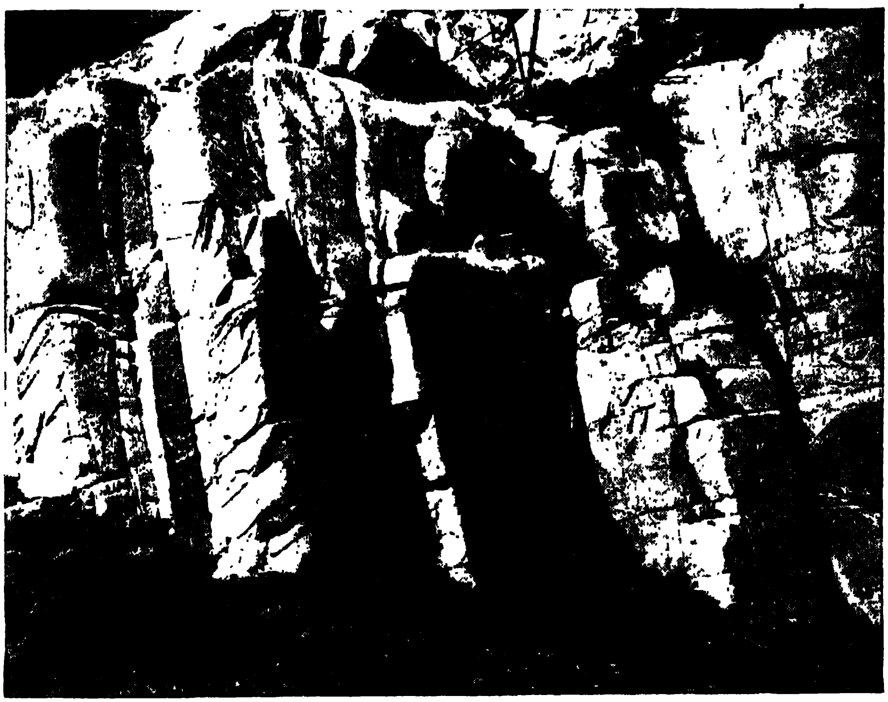

Fig. 134. Jointing in granite. Joint planes commonly occur in sets all the members of which trend in the same direction. The sets may be vertical, inclined, or horizontal. (*U.S. Geological Survey photograph.*)

but sometimes move along the plane of fracture and are displaced. Such displacements are called *faults*. The motion that produces the dislocation often is sudden but usually is limited in amount to fractions of an inch or a few feet. The displacement is sometimes in a vertical direction, the rocks on one side of the fault being elevated as compared with those on the other. Then a cliff is produced which is called a *fault scarp*. Some faults are produced by tensional or stretching forces as in Fig. 135*A*, *B*; others by compressional or crowding forces, as in Fig. 136. In some faults the displacement is horizontal rather than vertical, resulting in the breaking and offsetting of roads and boundary lines.

When many successive vertical faults occur along the same plane at intervals during thousands of years, the resulting escarpment along the line of the fault plane may attain the size of hills or even mountains (Fig. 137). Most of the Basin Ranges in Nevada are the result of tensional faults which have uptilted great masses of rock, and so is even the towering east face of the Sierra Nevada Range of California. The Lewis Range of Montana, in Glacier National Park, is likewise the result of faulting but of the compressional type, which caused the broken edge of the rock layers to slip up over the rocks of the adjacent plains and ride out upon them for a distance of several miles. These giant displacements required a long time for their accomplishment during which the growing escarpments were attacked by destructive agents, lowered, and carved up into mountain peaks (Figs. 135*C* and 136).

In a few places in the world parallel faults of great length have permitted the segments of earth between them to drop down. These become broad valleys, flanked on either side by fault scarps, and are known as *graben*, or rift valleys (Fig. 138). Of this origin are such famous valleys as the Lowlands of Scotland, the upper Rhine Valley, the depression in which the Dead Sea lies, and those vast trenches in East Africa occupied in part by lakes Tanganyika and Nyasa. In other places the land between parallel faults has been elevated rather than depressed. The result is a blocklike uplift called a *horst*.

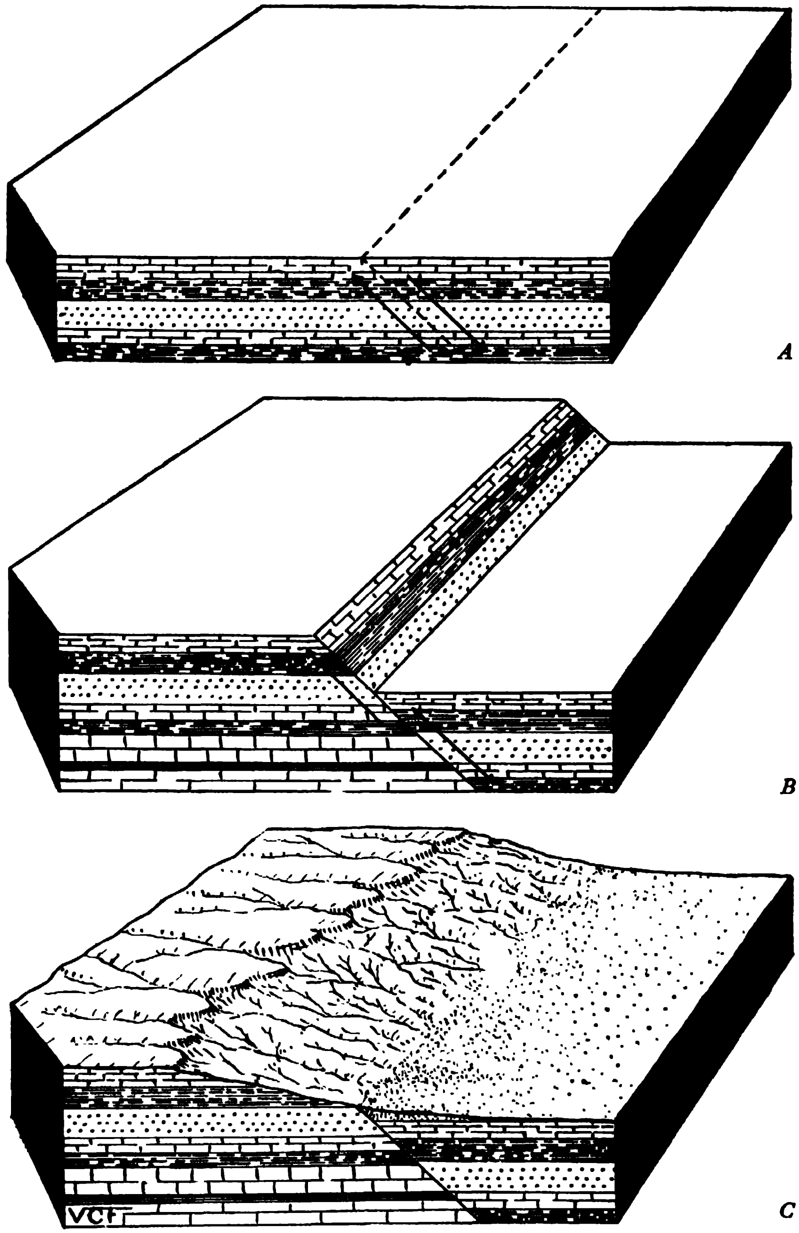

Fig. 135. Diagram to show the development of a tensional fault in sedimentary rock. *A*, The strata before faulting; *B*, fault, showing direction of displacement and the fault scarp; *C*, the reduction of the fault scarp by erosion to a dissected fault-line scarp.

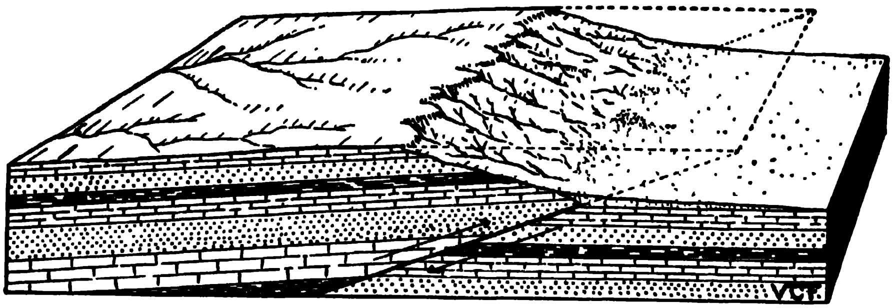

Fig. 136. A diagram to illustrate the manner of displacement in a compressional fault. The dotted lines show the volume of rock removed by erosion during the growth of the fault-line scarp.

Fig. 137. A recent step in the growth of a great fault-line scarp. Above is the front of the Wasatch Mountains, a great fault-line scarp. Parallel to it, the low scarp of a recent fault is shown by the dark line that traverses the piedmont alluvium. (*U.S. Geological Survey photograph.*)

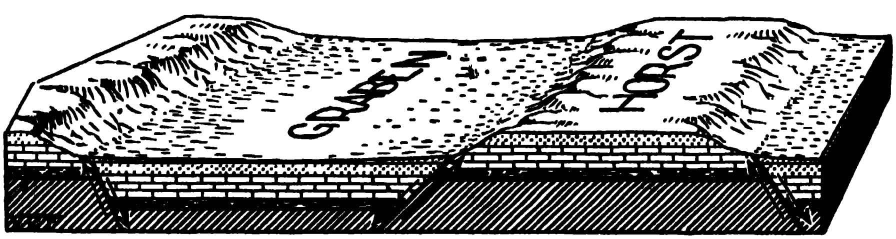

Fig. 138. A diagram to illustrate block faulting and the formation of a graben and a horst. The arrows indicate direction of relative displacement.

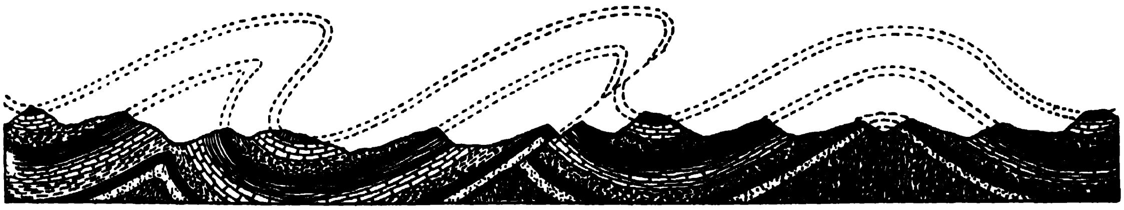

Fig. 139. Synclinal and anticlinal mountains. The complicated folds and faults of some mountains have been studied, and from the eroded remnants which make up the present mountains vastly greater structures have been projected. These probably never existed as such, because they were eroded as they were formed (see also Fig. 266).

Fig. 140. A portion of a buried anticlinal structure that has been exposed in a stream valley. (*U.S. Geological Survey photograph.*)

Some of the Basin Ranges are of that origin. To some extent faulting has a part in the making of almost all mountains.

347. Crustal Bending. In certain earth deformations the stresses have been applied to rocks so slowly or under such conditions that instead of fracturing they bend or even fold. The bends and folds may be either small or of mountainous proportions and either simple or complicated. In some mountain regions sedimentary rock strata have been shortened by horizontal compression and have been pushed up into a series of wavelike folds (Fig. 139). The arch, or crest, of one of these simple folds is called an *anticline*, and the trough of the wave a *syncline* (Fig. 140). In the Alps and some other mountains the folding has been so intense as to cause the wavelike structures to close and tip over. In most folded mountains the arrangement of the rocks is further complicated by the fact that severe folding has been accompanied by faulting and, in many places, by intrusions of igneous materials also. The present mountains of highly folded regions seldom reproduce anticlines and synclines in corresponding ridges and valleys because time and the degradational processes have intervened, greatly altering the appearance of these structures. However, the

attitudes of the remnants of the folded rocks, resistant and nonresistant, are generally reflected in features of mountain relief.

348. Crustal Warping. Similar to folding in nature, less intense, but even more important are broad deformations of the earth's crust which may be called warping. Such changes in crustal shape affect vast areas and probably are continuously in progress, but they require thousands of years to produce notable results. Through warping, broad areas of low plains land, such as formerly existed on the present site of the North Sea basin, have been lowered slowly a few feet or a few scores of feet and added to the shallow sea bottoms. By the same process great expanses of shallow sea bottom have been elevated slowly and added to the areas of the continents. Most of the state of Florida is a relatively recent addition to the area of North America. Through an understanding of this process one comes to an appreciation of the meaning of the stratified sedimentary rocks, containing the fossil remains of sea animals, that now are found far in the interiors of each of the continents. The fossil evidences in these rocks indicate that some of them were uplifted from the sea far back in geologic history, others in comparatively recent time. Similar evidence shows that some areas have been alternately elevated and depressed relative to sea level not only once but several times.

349. Diastrophism and Rock Structures. From the foregoing it may be seen that the attitudes and arrangements of the rocks are subject to the greatest variation. Sediments put down horizontally do not always remain so. Likewise, igneous rocks are subject, long after their formation, to distortion and fracture. The position and arrangement of rock formations with respect to each other is called the *rock structure*, and rock structure is one of the very important elements in that complex of conditions out of which landforms are evolved.

350. Regions of Present Diastrophism. Although the records of the rocks seem to indicate that all parts of the earth have been subjected to warping, folding, or faulting at one time or another, not all are now subject to equally great diastrophic changes. Instead, these processes seem to be more active in clearly recognized regions or zones. Most important of these are the borders of the Pacific Ocean. There, offshore, is a series of notable ocean deeps, while onshore are systems of mountains: the Andes, the coastal mountains of North America, Japan, and the Philippine Islands. These two, the deeps and the fringing heights, appear to be under constant stress and are subject to frequent readjustment. This is expressed in numerous faults, geologically recent, which appear to result from the elevation of the lands relative to the adjacent ocean bottoms. Other areas of recurring change are found in the West Indian region and in a long zone extending from Polynesia and the Pacific borders through the East Indian region westward across southern Asia and southern Europe.

VULCANISM

351. Volcanic Activity. Vulcanism is a term applied to all those processes by means of which molten rock is transferred from deep-seated sources to or toward the surface of the earth. Although the products of vulcanism include steam and gases as well as molten rock and solid fragments, the latter are of greater environmental significance since they are the direct or indirect cause of several classes of landforms.

352. Igneous Extrusions. The principal product of volcanic extrusion is lava, or molten rock. Some lavas are composed of highly siliceous, acid-rock minerals which quickly become viscous and solidify as they approach the surface or before they have flowed far. Extrusions of these sometimes are accompanied by poisonous gases and steam which find difficult escape through the viscous mass and cause *explosive* eruptions. The explosions hurl bits of lava, blown to fragments, high into the air. These cool suddenly and settle close about the vent, or *crater*, in different forms called volcanic ash, cinders, pumice, or slag, intermingled with flows of viscous lava. This produces a steep-sided cone which ultimately may attain mountainous proportions. This process is well illus-

CHAPTER 13: *The Agents and Processes of Gradation*

358. Gradational Agents and Processes. It has been noted previously that the tectonic forces are opposed by forces of gradation which tend to reduce to a low and uniform level all those features produced by diastrophic uplift or volcanic outpourings. Most important among the *agents* that accomplish this work are water, ice, and wind. They derive their energy from the sun and are continually acted upon by the force of gravity. The energy of the sun evaporates the waters of the oceans, which are then precipitated upon the land and returned to the sea as running water or moving ice. Solar energy and the force of gravity likewise are responsible for the winds, which remove some quantities of earth from the land surface and which largely condition the precipitation of moisture over the lands and the work of waves along the margins of the seas. Organic agents such as plants, animals, and man play parts in the slow gradation of the land, but their activities also are conditioned by solar energy, particularly as it is expressed in climates.

The agents of gradation work in many ways to accomplish their objective. It may help to understand them if it is observed that the processes are of two somewhat different types, although they are so intimately related that often it is difficult to determine at just what point one type of process ends and the other begins. Certain processes are completed without motion, their products remaining essentially where they were originally. They may be called the *static processes*. The completion of other processes necessarily involves motion during which material is picked up, transported, and put down. These may be called *mobile processes*. The static processes prepare rock for removal; the mobile processes bring about its removal and cause its redeposition. The latter are the processes of *degradation* and *aggradation*.

359. Landforms Mark Stages in the Gradational Process. By whatever agent the mobile processes are accomplished, material is removed from higher elevations to lower and most of it ultimately to the sea. During the process of removal the same material may be picked up and put down many times, each time a step being accomplished toward the ultimate destination. The intervals of deposition during the process of removal differ greatly in length. A bit of silt or gravel carried by a stream may be lifted and put down a hundred or a thousand times in a single day only to be cast into a by-water and there to lie a hundred or a thousand years before being moved again.

Many kinds of landforms originate from steps and incidents in the gradational process. Some of them are forms carved in the solid rocks of the earth's crust by the agents of degradation. Others are formed during aggradation by the temporary (in the geological sense) deposition and peculiar arrangement of material on its way to the sea. In the development of landforms, both the degradational type and those made by aggradation, conditions of climate are of the greatest importance.

The Static Processes

360. The Breaking Down of Rock. Before the solid rock of the earth's crust can be removed, portions of it must be disintegrated, decomposed, or otherwise made ready for removal by the agents of gradation. The processes by means of which this is accomplished

Fig. 145. Weathering granite. The disintegration of granite in place, here in a spherical manner, is accomplished by the decomposition of certain of its constituent minerals. (*Wisconsin Geological Survey photograph.*)

are called *weathering*. Weathering may be either chemical or mechanical in nature. Chemical weathering may be said to include all those processes of rock decomposition or decay in which some of the rock minerals undergo chemical change. Mechanical weathering includes all those processes by which solid rock is disintegrated, or reduced to fragments, but left chemically unchanged. Often one is more important than the other, but usually both are to some degree involved in the preparation of rock material for removal.

361. Chemical weathering results principally from the chemical union of oxygen, carbon dioxide, or water with elements in the rock minerals or from the dissolving of some of them. These chemical processes are called, respectively, (*a*) oxidation, (*b*) carbonation, (*c*) hydration, and (*d*) solution. They are of great importance because the chemical changes result in the formation of new minerals which have properties different from those from which they were derived in size, shape, hardness, or degree of solubility. These changes greatly affect the rate at which solid rock is prepared for removal by the mobile processes (*a*) by producing new minerals which are less resistant than the old to the processes of removal or (*b*) by the disrupting effect caused by the crowding of expanding substances. The rusting of iron is a familiar example of both oxidation and hydration, for yellow iron rust is a hydrous oxide of iron. Some igneous rock minerals contain iron, and many sedimentary rocks include iron oxide as a cementing material. These minerals are subject to oxidation and hydration and are changed thereby. Other of the igneous-rock minerals contain combinations of elements such as potassium or calcium which, under favorable conditions, recombine with the carbonic acid in ground water. The resulting carbonate crystals are larger in size and different in shape from those of the original minerals. This change exerts a strong wedging force, tending to crowd apart the associated rock crystals and, therefore, to weaken or break up the crystalline structure of the rock (Fig. 145). Hydration tends to produce the same result, being attended, accord-

ing to Merrill, by an increase in the bulk of some minerals of as much as 88 per cent. Solution works in a different way. Certain minerals, such as calcium carbonate, are changed by weathering and become soluble in the water of the ground. Their removal in solution is called *leaching*. It leaves the rocks that contained them somewhat porous, or at least less solid and resistant than before, and the process may end in the nearly complete disappearance of such rocks as are composed largely of soluble minerals.

The chemical decomposition of rock is not local but widespread in its effects. It operates not only upon crystalline igneous rocks but upon those of sedimentary origin also (Fig. 133). Rain water in falling through the air absorbs carbon dioxide gas and becomes a dilute carbonic acid. In the ground it obtains other acids from decaying vegetation. In general, therefore, the water of the ground is really a weak acid and is capable of dissolving lime and other substances and of making chemical changes not possible in pure water.

All the processes of chemical weathering are promoted by high temperatures and abundant moisture. Chemical weathering is, therefore, most rapid and complete in the humid tropics and least rapid and complete in regions of aridity or cold. Different rocks and even different parts of the same rock weather at different rates even under the same general conditions. Therefore, after prolonged weathering some parts of a rock may be greatly changed while others are so little changed that they stand out in bold relief after the weathered material is removed. Such features are said to be the result of *differential weathering*.

362. Mechanical Weathering. Although the processes of chemical decomposition are the most important of those by which rock is made ready for removal by the agents of gradation, there are several processes of mechanical disintegration also. The following are some of the more effective of them: (*a*) The formation of joint planes by diastrophism is a kind of mechanical weathering. The fractures so produced often are the zones of attack for other weathering agents. (*b*) All scraping, grinding, and scouring, sometimes called abrasion or corrasion, are weathering processes. (*c*) The expansive force of freezing water in rock crevices pries apart the adjacent minerals with a force that, under ideal conditions, is much greater than the pressure in a steam-engine boiler. (*d*) The growth of plant roots in rock crevices exerts a wedging force of surprising proportions. (*e*) The intense heating of rocks, as by forest fires, and their sudden cooling cause internal stresses which end in rock disruption. It may be that intense insolation and rapid cooling, as between day and night in desert climates, is sufficient, when repeated for many years, to accomplish a similar end. However, it seems unlikely that the latter process is the principal cause of rock weathering even in deserts, as was formerly believed. Mechanical weathering probably takes place in warm and humid regions, but its products are to a considerable degree obscured by the more abundant products of chemical weathering. It is in regions of cold and arid climates, where the chemical processes operate slowly, that the rock fragments produced by mechanical means attain their greatest relative importance. In these regions coarse and angular materials comprise a large part of the regolith.

The accumulated materials resulting from weathering and awaiting transportation often cover to some depth the parent rocks from which they have been derived. These accumulations make up a part of the mantle rock or regolith previously noted (340).

The Mobile Processes

363. Erosion. The weathering processes commonly are followed, but not always immediately, by *degradational* processes which remove the weathered rock fragments from the places of their origin. Specifically, these include the picking up of loose material and its transportation. These processes combined are called *erosion*. The processes of weathering and erosion together produce the general result of degradation, which is the wasting away of the land and its reduction down to the ultimate lowest possible slope, or grade, with respect to sea

level. The principal agents of erosion were listed above, but they may be repeated here, since they will be used as a basis for organization in the remainder of this discussion of the agents and processes of gradation. Weathered rock is transported by the force of *gravity* which may act either directly or, on a broader scale, through the agencies of the *water in the ground, running water, moving snow and ice, waves, and wind.* To a small degree transportation is accomplished also by organic agencies, including human agency, and in other minor ways. It will be clear that *transportation* is the essential element of erosion. It may be noted also that transportation is accomplished whether the material (*a*) is carried in dissolved, and therefore invisible, form or (*b*) is lifted bodily and carried in suspension by wind, stream, wave, or ice or (*c*) merely rolls, slides, or is pushed downslope by any of these agents or by gravity itself.

The rate at which weathered material is transported by the agents of erosion obviously bears a close relation to the degree of slope of the land surface on which it rests. On steep cliffs gravity itself removes weathered rock fragments about as fast as they are loosened. This leaves the rock of the cliff bare. On flat surfaces, even in rainy regions, the products of weathering tend to accumulate to greater depths because of the slowness of the processes of transportation there. In such situations the accumulated regolith may grade downward from fine surface materials, which are completely changed by chemical and mechanical weathering, through partly changed and coarser fragments into the unweathered parent rock beneath. In the humid tropics, where chemical weathering is most active, the regolith is porous, and the surface is protected from erosion by a thick covering of vegetation. There the regolith may accumulate on some gentle slopes to a depth of 100 ft. or more. In most regions it averages considerably less than that depth and in some places is thin or nearly absent.

364. Deposition. Since each of the agents of erosion, under proper conditions, is capable of transporting material, it will be evident that, under other conditions, they will put it down again. This process may be called *deposition.* By it *aggradation* is accomplished, and elevations below the local grade are brought up to it by filling. Just as materials are carried in different physical conditions and by the different agents, so they may be deposited either from solution or from suspension, or they may merely come to rest after having fallen or slid some distance. They may be deposited by the wind, by running water, by moving ice, or by the waves. The various agents and conditions combine to produce classes of deposits which often are related to the development of distinctive landforms or other features of the natural equipment of areas.

From these general considerations the discussion may turn to the specific gradational agents and the various processes by which each carries on its work and aids in the development of landforms. The emphasis in this brief survey will be upon the nature of the *processes* involved. Description of the features produced, the principal concern of the student of geography, will be reserved for more detailed consideration in other connections.

Ground Water and Its Gradational Processes

365. Ground water exists in the pore spaces of the regolith, in porous rocks, and in the joint cracks and other crevices of all rocks, in regions of humid climate, as far down as crevices and pore space extend. The greater part of the pore space, and therefore of the water, is within a few hundreds of feet of the surface, and many impervious or tightly capped rocks at great depths are essentially dry. The ground-water supply is maintained from the land surface by that part of the precipitation that seeps into the ground rather than immediately running off in streams or evaporating into the air. The surface addition of water seeps downward, as it would in a glass full of sand, until it joins with that already in the ground and fills the lower spaces first. Ordinarily there is not sufficient water to fill all the pore space, and the upper part of the earth is merely moist while the lower part is

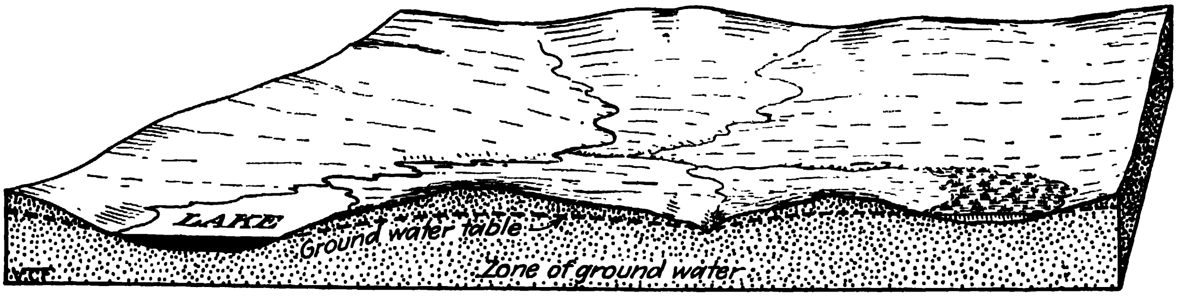

Fig. 146*A*. A diagram to illustrate the undulating surface of a ground-water table and its relation to the land-relief and drainage features.

saturated. The top of the saturated zone is called the *ground-water table*, or ground-water level. In areas of uniform rock character it is not a horizontal surface but tends to seek a common level by slow outward movement from its higher portions (Fig. 146*A*). It is not found at a uniform depth below the surface but is usually at greater depths beneath hills and at less depths below valleys, at greater depths after protracted droughts, and at less depths after rains. In humid regions it may be near the surface, and in arid regions far below it. In areas underlain by complex rock structures, the average depth of the ground-water table beneath the land surface may be irregular, some of the rocks being more permeable than others. In some compact rocks, owing to the capillary movement of the water upward in the small pore spaces, there may be no definite ground-water table but merely a gradual decrease in degree of saturation upward from the fully saturated horizons underneath. Even where the ground-water table is definite, it seldom remains long at any given depth beneath the land surface. In wet seasons or cycles of wet years it rises because of abundant additions from above. In dry seasons or cycles of dry years it sinks to lower levels because the rate of seepage and other losses exceeds the rate of addition. As a consequence three horizons may be recognized: (*a*) an upper one which seldom if ever is saturated, (*b*) a deeper one which always is saturated, and (*c*) an intermediate one which sometimes is and sometimes is not saturated. This condition has much to do with the permanency of springs and wells (554, 557).

366. The gradational work of ground water is accomplished through both chemical and mechanical processes. However, the chemical processes are undoubtedly more widespread, penetrate the earth more deeply, and bring about greater total changes. In most rocks the ground water moves too slowly to accomplish much mechanical erosion, but it is effective in promoting landslides or soil flowage and the slow downslope creep of the regolith (Fig. 146*B*). This it does by increasing the weight of the weathered material and by acting as a soil lubricant. The chemical effects of ground water on landforms are accomplished largely through (*a*) solution and (*b*) the redepositing of dissolved minerals.

Solution is a widespread phenomenon. It has been discussed as a phase of chemical weathering, and that perhaps is its most significant aspect. It is, however, a process capable of giving rise to certain landforms. In regions of pure limestones especially, underground solution may remove rock to the extent that large caverns are formed or the rock is honeycombed with small cavities and the surface is dotted with depressions caused by solution cavities or by the collapse of cavern roofs (408). Such regions are said to have *karst* features, and in them a large part of the drainage flows in underground channels rather than in surface streams.

Under favorable conditions ground water may become overcharged with dissolved minerals and be forced to deposit some. These conditions include (*a*) evaporation of some of the water, (*b*) decrease in its temperature, (*c*)

Fig. 146*B*. Slumping and earth flow resulting from rain saturation of the ground on a shaly hill slope in eastern Ohio. The lower slope shows turf rolls resulting from flowage, and the upper shows tension cracks. (*U.S. Soil Conservation Service photograph.*)

loss of some of its dissolved carbon dioxide, and (*d*) changes in other conditions that tend to hold minerals in solution. The deposited minerals are chemical precipitates, comparable to those which accumulate in a teakettle. In a somewhat different way, minerals are deposited from underground water also by chemical exchange with other minerals in the rocks through which the water passes and by the work of micro-organisms. The process of deposition is accomplished slowly, molecule by molecule. A well-known illustration of it is the formation of stalactites and stalagmites which grow in underground caverns through precipitation from percolating water. Of much greater importance are certain less spectacular phases of deposition. For example, ground water charged with lime may build a lime filling in the pore spaces of a bed of sand, cementing the grains of sand together into a limy sandstone. Or water charged with silica may remove the molecules of a previously deposited lime cement, replacing them with the silica, thus producing a quartzite. In the same manner silica or lime, either alone or in combination with valuable metals, such as gold, may be deposited in a rock crevice, making a *vein* (692, Fig. 147). Wood, bone, or shells are *petrified* by the removal of their substance, molecule by molecule, and its replace-

Fig. 147. A vein of white quartz traversing wave-worn metamorphic rocks on the Maine coast.

ment by lime or silica, even the microscopic details of internal structure often being kept.

The removal and replacement of minerals by ground water are important factors in the formation of certain earth resources, such as soil and mineral ores, as well as in the making of landforms. In humid regions the lime and other soluble substances, including plant foods, are removed from soils by solution, leaving the soils leached and often poor. In arid regions a lack of ground water is a cause for lack of leaching and a widespread accumulation of these same substances in the soil. In some regions of rocks bearing considerable amounts of valuable minerals the richness of the mineral ores has been increased greatly by the solution of silica and other associated substances, leaving the valuable minerals in concentrated form. Other valuable ores have been enriched by the opposite kind of process, in which small quantities of mineral are selected by ground water from large masses of rock and are brought together in more concentrated form. Since these changes take place so slowly, it follows that a vast amount of time is required for their accomplishment.

Running Water and Its Gradational Processes

367. The Origin of Streams. Running water has a larger part than any other of the agents of gradation in the modeling of landforms. Some of the work is done by the rain directly or by thin sheets of water moving over the ground during downpours of rain, but the larger part is done by streams, because in them the water is deeper and has more inherent force. Streams are fed (*a*) by the immediate runoff of water during rains; (*b*) by the underground water issuing through seepage and springs; and (*c*) by the release of water temporarily held in storage in lakes, swamps, snow, and glaciers. The turbulent force of running water over the land surface dislodges and removes weathered rock, and in the process it develops channels or valleys. It is the patterns and peculiarities of stream-cut channels and valleys that give characteristic details of relief to most of the lands of the earth. It is evident that since the number and size of the streams of a region depend much upon its supply of precipitation, so, therefore, do many of the peculiarities and characteristics of its landforms.

DEGRADATION BY RUNNING WATER

368. The Erosional Work of Streams. The most widespread degradational activity of running water is accomplished by the hydraulic action or surface wash of the *runoff*, which is that part of the precipitation that does not at once soak into the ground or evaporate into the air. The runoff may start its work as a sheet of water, but ordinarily it does not progress far before it is concentrated into rivulets which eventually are enlarged and are maintained by springs and the seepage of underground water. Streams flow in valleys, and most valleys start as gullies. It is the work of running water to make them *longer*, *deeper*, and *wider*. A normal gully begins at the base of a slope and grows in length by erosion at the point where surface water pours in at its upper end. In a sense it gnaws its way *headward* into uneroded land (Fig. 148). New gullies branch from the sides of the first one and lengthen in the same manner (Fig. 149). In rock or regolith of uniform resistance the gullies normally have a branching, treelike, or *dendritic*, relation to each other (Fig. 262). Gullies of this kind may grow on unprotected slopes in such numbers as to create a great problem in the control of soil erosion (650). Not all the gullies thus formed grow to great length, but in time some of them may. During that time each long gully will have acquired tributaries, each tributary will have subtributaries, and these in turn will end in a multitude of gullies which reach and drain all parts of the region. A major stream of water and all its tributary streams is called a *river system*. The elongate depression that each stream cuts for itself is called its *valley*. The higher land separating two adjacent stream valleys is called an *interfluve*. The valley of the major stream and all its tributary valleys and gullies are called a *valley system*. The entire area of land drained by a river system is called a *drainage basin*. The line along an upland separat-

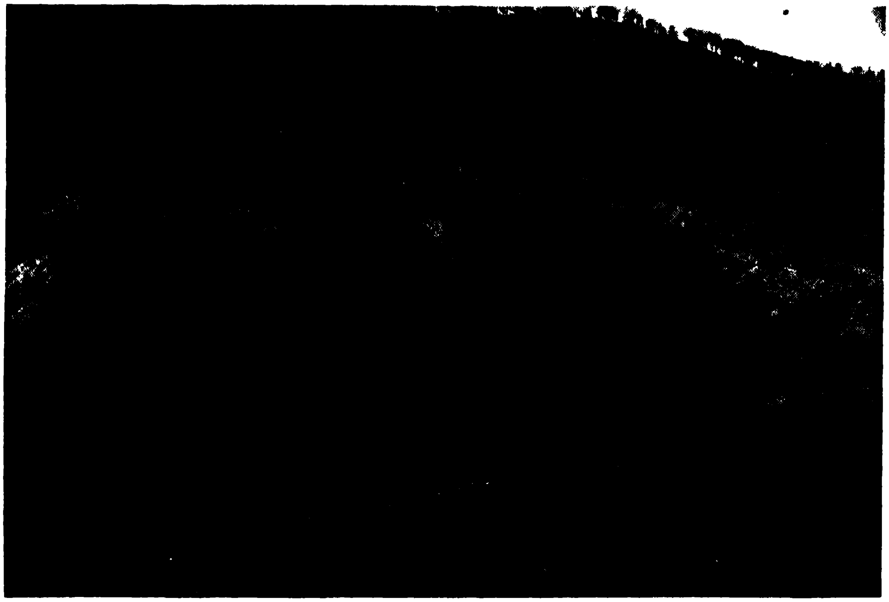

Fig. 148. A gully head which is almost visibly gnawing its way up a slope which directs the flow of rain water into it. (*Photograph by F. W. Lehmann, C. B. & Q. Railroad Company.*)

Fig. 149. As a gully grows in length by headward erosion, tributary gullies branch from its sides and grow in like manner. (*Photograph by F. W. Lehmann, C. B. & Q. Railroad Company.*)

ing two adjacent drainage basins is called a *divide*. On the divide surface drainage destined for the respective streams is parted, as on the ridge of a house roof, although some divides are low, and the line of water parting is therefore indistinct.

Valleys are deepened when their streams, through the churning effect of hydraulic action, loosen rock materials in their beds and by using silt, sand, and stones as tools scour or abrade their beds and transport the materials thus provided. In this process some of the rock minerals are dissolved also, and the tools are themselves worn, rounded, and reduced in size. The rate at which a stream is able to deepen its valley depends upon (*a*) the velocity of the running water, (*b*) the volume of the stream, (*c*) the nature and abundance of the tools available to it, and (*d*) the resistance of the material into which the valley is being eroded. The velocity of a stream is determined, in turn, by several conditions among which the most important is its *gradient*, or the degree of the head-to-mouth slope of its bed. Streams with steep gradients are swift and are able, given tools, to deepen their valleys more rapidly than other streams of similar volume but with lower gradients and, therefore, lower velocities. In a river system the newer tributaries and headwater streams usually have steeper gradients than the waters of the middle and lower courses where erosion has been longer in process. For that reason the tributary streams may be eroding rapidly while the main stream, in its lower course, may have a gradient so low that it is no longer able to cut downward, and more material collects in its channel than it is able to transport. The carrying capacity of a stream increases rapidly with increase in the velocity, and if its velocity is doubled, the maximum volume of the pieces of rock it will be able to move may, under ideal conditions, be increased in proportion to the sixth power of its velocity, or sixty-four times. According to Geikie, a stream having a velocity of about $\frac{1}{8}$ mile per hour will barely move fine clay. At a velocity of $\frac{1}{4}$ mile per hour it will move fine sand; at $\frac{1}{2}$ mile, coarse sand; at $\frac{2}{3}$ mile, fine gravel; and at $1\frac{1}{2}$ miles per hour it will transport pebbles about an inch in diameter. When any part of the stream has deepened its channel to a gradient so low that it flows sluggishly and is barely able to transport the material supplied to it by its tributaries, it will deposit sediment temporarily in its valley bottom. It is said then to be a *graded stream*, or a stream at grade. If time is permitted for a stream to continue, without interruption, the extremely slow process of erosion below the level of grade, it will reach ultimately the lowest gradient at which it can flow. Then it will be unable to transport any material and therefore unable to degrade its valley further. Such a stream is said to have reached its *baselevel*.

Not all graded streams, however, have reached the lowest levels to which they are ultimately capable of eroding. Many are prevented from continuing their downward cutting by the existence of *temporary baselevels*. Thus, for example, some of the streams of northern Ohio have the characteristics of graded streams because they empty into Lake Erie, the elevation of which establishes a baselevel for them. This, however, is, geologically speaking, temporary, since the level of Lake Erie is maintained by a resistant rock ledge at Niagara Falls, and below this are the rapids of the St. Lawrence River. In time these obstructions may be removed by erosion (provided that diastrophic uplift does not offset the reduction of the surface by erosion), and then the tributary streams in Ohio will be able to reduce their channels to the ultimate and lowest possible grade, which is established by the level of the sea. The same is true of certain arid-land streams which do not ultimately discharge into the sea but into basins of interior drainage (454). The floor of such a basin, whatever its elevation above sea level, establishes a temporary baselevel for the streams tributary to it.

369. The Characteristics of Young Streams and Their Valleys. Streams that have just entered upon their work of erosion and still have rather steep gradients are called young streams. They are cutting more vigorously downward than laterally but have much to do before they reach their baselevels (Fig. 150*A*).

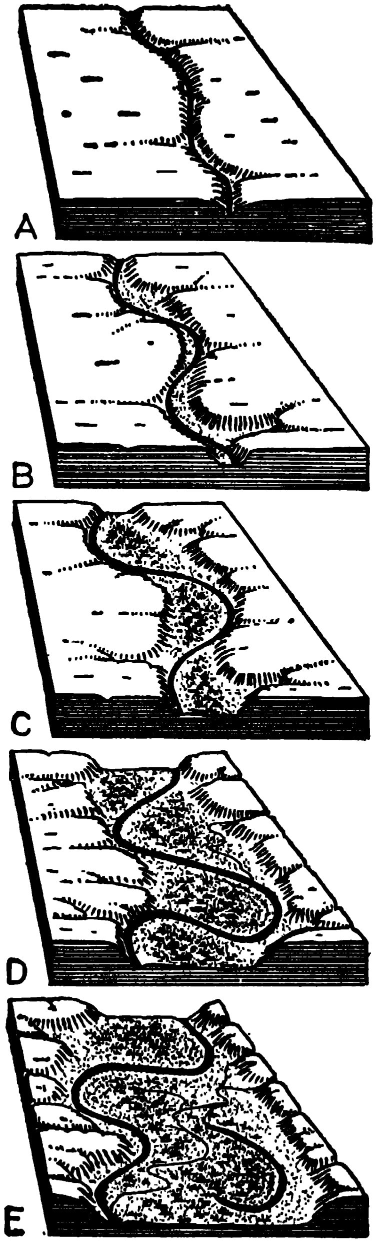

Fig. 150. Diagrams illustrating changes in the transverse profile of a valley. *A*, the V-shaped profile of a young valley; *B*, the start of meandering; *C*, retreat of valley bluffs; *D* meander belt and long meander; *E*, meander cut off and floodplain widened by trimming of bluffs.

While the downward cutting is in progress the valley is widened at the top as material from its sides falls or slides into the stream or is carried in by rainwash. The transverse profile of the young valley is therefore *V-shaped* (Fig. 285). In loose material, which washes or slides easily, the V is likely to be broad and open, while in hard rocks it is likely to be narrow and gorge-like (Fig. 283). In regions of high elevation young valleys of the gorge or canyon type may be hundreds or even thousands of feet deep, while in regions of low elevation they may be only a few feet in depth, although their shapes are similar. Both are young in terms of stage of development, although there may be a vast difference in their ages measured in terms of years.

Young streams rapidly eroding often find their courses through rocks of unequal resistance, which erode at different rates. The abrupt changes in gradient, which result from the *differential erosion*, cause the courses of many young streams to be interrupted by waterfalls and rapids. In older streams, which are nearing grade, time has permitted erosion to carve away even the hardest rocks, and the falls and rapids tend to disappear (Fig. 151).

370. The Characteristics of Mature Streams and Their Valleys. As a stream approaches baselevel, the limit of its downward erosion, both stream and valley take on new characteristics. The stream, its gradient decreased, becomes less swift and is readily turned aside. It begins to swing against its valley walls, cutting at their bases and pushing them apart by undercutting them. Widening becomes more rapid than deepening, and the stream ceases to be direct but swings from side to side on a widening valley floor in broad loops or *meanders* (Fig. 150*D*). The valley ceases to be narrow and V-shaped and acquires width and a flat valley floor as a result of its continuous shifting of position and trimming of the valley walls.

371. Stages of Erosional Development. As stream valleys develop so do the relief features of the regions through which they flow. In areas where the streams generally are young the valleys are narrow, the tributaries are undeveloped and few, and the interfluves are broad and little dissected (Fig. 152*A*). It is evident in such areas that the streams have only well begun the task of reducing the whole block of land to its ultimate low baselevel. A

AGGRADATION BY RUNNING WATER

372. How Streams Deposit Material. If the supply of weathered rock available for stream transportation exceeds the carrying capacity of the stream it becomes overloaded, and some of the load will be deposited. The term *alluvium* is applied to stream deposits of all grades and forms of accumulation. The action of running water tends to sort the transported material roughly according to the size and weight of its particles before putting it down. This sorting action causes stream deposits to accumulate as beds of gravel, sand, silt, and clay. In the process of deposition streams put down the coarsest and heaviest parts of their loads first, because they carry such material less easily. Thus the principal deposits of a swift Rocky Mountain tributary of the Mississippi system may be large stones and boulders, while those of the lower Mississippi itself are only fine sands, silts, and clay. However, the carrying power of a stream changes often between flood and low water, and it is common to find beds of alluvium of different grades one above another.

Streams become overloaded in several ways, such as (*a*) by having much new sediment brought to them without corresponding increase in carrying power or (*b*) by loss of water through decrease in rainfall, through seepage, or through evaporation. However, it is likely that the most common cause for stream deposition is loss of velocity. Decrease in stream velocity may come about gradually, as a result of the decreasing gradient from the headwaters toward the mouth, or it may come about suddenly. A sudden decrease in velocity may occur at an abrupt change in land slope, as, for example, where a mountain stream flows out upon a flat plain, or it may occur as a result of the checking of the stream current where it enters a body of standing water, such as a lake or the sea.

373. Where Streams Deposit. The different conditions that cause streams to deposit

Fig. 153. The small stream shown here is widening its valley. The cut bank on the outside of a meander bend is slumping into the channel which is deepened by turbulent flow. Material is being deposited (foreground) on the inside of the bend. (*Photograph by F. W. Lehmann, C. B. & Q. Railroad Company.*)

cause the deposited materials to accumulate in several characteristic places, with reference to the stream course and in several commonly recognized forms. The places of deposition may be noted here, and the forms assumed by the different kinds of deposits may be left for later and fuller consideration.

On Valley Flats. A stream is likely to deposit some of its overload in its own channel, often on the inside of a bend where the velocity of the water is least. It is there that *sand bars* or similar deposits of mud or gravel accumulate. Their formation is a normal part of the development of an aging stream. The formation of many sand bars chokes the stream channel and increases its tendency to flood in times of high water. Gradually, by undermining and caving the valley wall on one side and depositing on the other, the stream produces the broad valley flat of old age and at the same time covers the flat with river sediment (alluvium) (Fig. 153). Such a valley flat, covered with alluvium, is called a *floodplain* (Fig. 150).

When a sediment-laden stream rises in time of flood, overflows its channel, and spreads out upon the floodplain, much material is deposited immediately along the stream banks where the water first goes out of its proper channel and loses its velocity. There the alluvial accumulation is thickest, and it generally forms low, broad ridges bordering the stream. They are called *natural levees.*

At the Stream Mouth. Nearly all streams are able to carry some sediment down their entire courses and out at their mouths. Usually most of that sediment has been a long time on its way, having been incorporated into bars and floodplains, re-eroded, put down, and picked up thousands of times on its slow journey. Finally it is deposited where the stream velocity is checked upon entering a lake or the sea. Extensive accumulations of sediment in that kind of location are called *deltas.* Not every stream has a delta. Some carry out little sediment; others deposit their loads on sinking coasts or upon such as have deep waters or are so exposed

Fig. 154. The conformation of a small and fairly steep alluvial fan in Nevada. The apex of the fan lies at the mouth of the gully from which the fan material was eroded. (*Photograph by John C. Weaver.*)

to violent wave and current action that the sediment is spread over the adjacent sea floor and thus is prevented from making large accumulations.

The process of delta building is accomplished by addition to the banks of the stream during overflow and by the elongation of its channel through deposition at its end. The elongation produces a flat, fingerlike extension on the coast which lowers the stream gradient so much that presently it breaks over its banks and takes a new and shorter course to the sea, only to repeat the process. Thus the stream acquires more than one exit, and these are called its *distributaries* (Fig. 178).

At Sharp Decreases in Valley Gradient. The velocities of mountain streams are checked suddenly where their courses extend out upon adjacent plains. It is at this point that some streams choke their own courses with alluvium, turn aside and choke again, and repeating the process, ultimately build broad fan-shaped or conical piles of alluvium which are called *alluvial fans* (Fig. 154). In humid regions many mountain streams have sufficiently large and constant volumes to be able to move their loads of debris still farther down their courses and do not form alluvial fans. Even in humid regions, however, fans of large size accumulate at the bases of very steep mountain slopes, and those of small size often are to be seen at the mouths of small gullies where there are no permanent streams but where much water runs during a rain. Along a fresh road cut, on a sidewalk, or at the mouths of little gullies fans may be seen, perfect in shape but no more than a few inches across. It is in dry regions, however, that alluvial fans reach their greatest development. There the intermittent and frequently torrential flow of mountain streams favors the development of these forms, and they may grow until they reach a radius of several miles. Along the bases of some mountain ranges every stream has its alluvial fan, large or small, and they are so crowded that adjacent fans spread and join, making a continuous *piedmont alluvial plain* (Fig. 193).

Moving Ice and Its Gradational Processes

374. Mountain Glaciers. Glaciers, which are bodies of ice in slow motion, arise from accumulations of snow which, by the pressure of its own weight and by internal melting and refreezing, becomes consolidated into ice. The perennial snows of high mountains give rise to valley glaciers. Plunging avalanches carry snow from adjacent slopes into a valley head, where it attains great depths and gradually is transformed into loose, crystalline ice. Under its own great weight the thick mass settles, recrystallizes into solid ice, and expands, thus slowly pushing its lower portions down the valley. So long as the supply of snow is renewed from above, the glacier will continue to move.

The protruding ice tongue that creeps forward conforms to the shape of the valley in which it lies. Its rate of motion is governed by (*a*) the thickness of the ice, (*b*) the steepness of the valley gradient, (*c*) the temperature of the ice, and some other conditions. At most it is but a few feet per day. The advancing end of the ice tongue, extending down the valley, ultimately reaches lower elevations, where higher average temperatures prevail and the ice wastes by melting and evaporation. As long as the average forward movement of the ice is greater than the amount lost by wasting, the front of the ice tongue will continue to advance. When the rates of advance and wasting are equal, the ice front will remain in the same position. If a series of warm years increases the rate of wasting, so that it exceeds the rate of ice supply, the ice front will recede up the valley. The glacier is said then to be in retreat. It is, however, only the location of the ice front that retreats, for the ice continues to move downslope or at most remains stagnant. Some valley glaciers in high latitudes, for example in Alaska, are able to push so far down their valleys that they reach the sea. There, instead of melting away, their ends are continually broken off by wave undercutting and the buoyance of the sea water, and the pieces float away in the form of icebergs (Fig. 288).

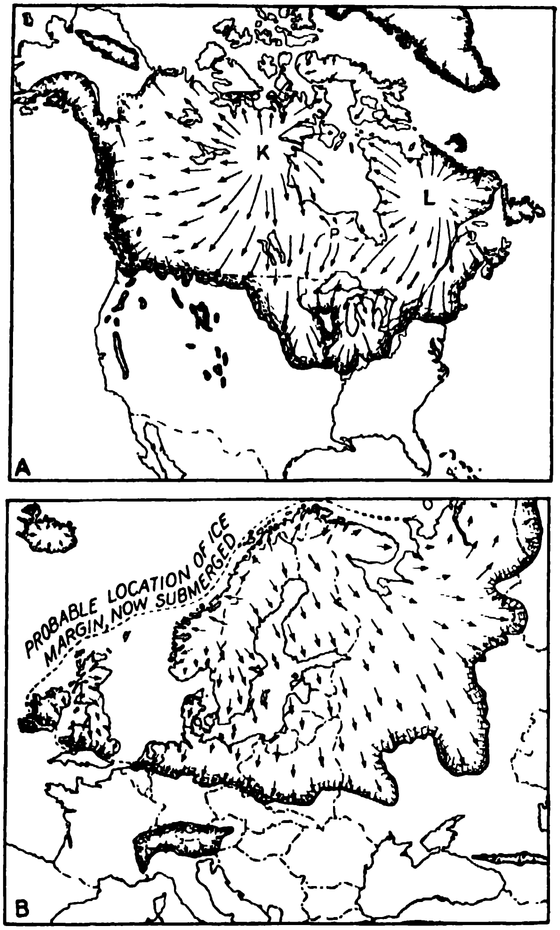

Fig. 155. The maximum extent of the continental glaciers of North America and Europe. *A*, the letters *K*, *P*, and *L* indicate the Keewatin, Patrician, and Labradorean centers of glacial movement; *B*, the principal center continental ice movement in Europe was in the highlands of Scandinavia.

375. Continental Glaciers. Great continental ice sheets, such as now occupy most of Greenland and Antarctica, formerly covered northern North America, most of northern Europe, and probably much of Siberia. A continental glacier is in some respects like a valley glacier but in others different. It starts with the accumulation of snow fields but not necessarily in regions of high altitude. Having attained considerable depth and area the snows are slowly transformed into ice, and the mass spreads outward under its own weight in all directions. It is fed by snowfall over its entire surface, especially at its margin.

It is a mistake to assume that the appearance of the great North American and European ice sheets must have been preceded or accompanied by climatic conditions vastly different from those of the present. The only requirement for continental glaciation is that the snowfall be just enough greater or the temperature enough lower than at present so that the snow of one year is not quite all melted when that of the next year begins to fall. If that condition prevailed the accumulation would spread inch by inch and century by century until its irregular margin reached a position where loss by melting and evaporation equaled the rate of advance. The disappearance of a great glacier, conversely, would result from a decrease in snowfall or an increase in temperature of an amount such that the average wastage exceeded the additions from snowfall. This would result in the eventual thinning of the ice, probably in its marginal stagnation and ultimate melting away. The time required for either the growth or the disappearance of a continental glacier has probably to be measured in tens of thousands of years. The reasons for the changes of condition that brought the glaciers into existence and later destroyed them are not definitely known.

The vast quantity of water locked up in these great ice sheets was, of course, extracted from the oceans by evaporation, and it returned to them upon the disappearance of the glaciers. It is believed that the quantity was sufficient to cause a general lowering of the level of the sea by at least several score of feet during the periods of glacier enlargement, and a corresponding rise in sea level during the periods of glacial shrinkage, including the present time. This would obviously have considerable effect on the areas of the continents and the shapes of their coastal outlines. Large areas of the continental shelves, now covered by shallow seas, may well have been land during a period of great glacial advance. Of these periods of alternate advance and retreat there are believed to have been several during the great ice age or Pleistocene Period (see Appendix E).

376. Areas of Former Continental Glaciation. The areas principally affected by the

most recent glaciation are shown in Fig. 155*A* and *B*. The European ice sheet radiated from centers located in the Scandinavian region and Scotland and extended southward into England, the Netherlands, Germany, Poland, and Russia. In Siberia, glaciers originating in the Ural Mountains, the northern uplands, and the far eastern mountains appear to have spread thinly over much of the intervening areas. It is possible that several of these coalesced into glaciers of great extent which were nearly contiguous. However, in the relatively dry environment of northern Siberia the ice sheets apparently did not attain such great thickness as did those originating in the centers of Scandinavia and Labrador, and perhaps they did not exist at all during the time of the latest ice advance in Europe and America.[1] The centers of North American glaciation were situated adjacent to Hudson Bay. From the American centers ice spread outward but more extensively southward. It reached to a line that trends from New York City westward across southern New York State to northeastern Ohio and from there nearly along the present courses of the Ohio and Missouri Rivers toward the Rocky Mountains. Adjacent to the glacier margins the ice may have been only of moderate depth, but it increased northward to thicknesses that may well have been a mile or more, sufficient at least to bury the mountains of New England. Within the glacial boundary the only district to escape burial beneath the ice sheets was a large area located in southwestern Wisconsin and adjacent parts of Illinois, and possibly of Iowa and Minnesota. It is known as the *Driftless Area*. At the time of the great continental ice sheets there were much larger glaciers in the mountains of both North America and Europe than now exist there.

377. How Glaciers Erode. Clean glacial ice is able to erode rock mainly by pushin , and by "plucking." Rock pinnacles or other unstable or detached rocks are readily toppled by the great weight of the advancing glacier, and loose earth is plowed up by it or frozen into the ice and carried forward. Even in solid bedrock, and especially on leeward slopes, the jointed or fractured blocks are wedged apart and frozen about with ice and are quarried or plucked from their seats. Using as tools the rocks thus obtained, the ice is able to accomplish another, and equally important, part of its erosion by the process of *abrasion*. Angular boulders, pebbles, and sand which are frozen fast at the bottom of the ice are held down by its great weight and pushed forward by its irresistible force. In their slow motion they gouge, groove, scratch, and polish the rock surface over which they pass. In the process the tools are themselves scoured, scraped, and reduced in size. They lose their sharp angularity and become partially rounded, or "subangular" (Fig. 205). Long-continued glaciation has in many places accomplished notable erosion, but, in general, the resulting features are not of so great an order of magnitude as those of stream erosion. Rather, they appear to be, in the main, the reshaped features of previous stream erosion.

378. How Glaciers Deposit. The load of a glacier is comprised of rocks and earth intermingled without regard to size or weight. It is carried in part upon the ice surface or frozen into its mass, but even more largely in its bottom, because that is where most of it is obtained. The lower layers of ice in some glaciers are so crowded with clay, sand, and boulders that the earthy material is more abundant than the ice. When its bottom is so greatly overloaded the glacier readily loses its frozen grasp upon some of the material which then is left resting upon the ice-scoured bedrock below. Upon the top of this deposited layer the still-burdened ice creeps slowly forward. During the final stagnation and wasting away of a glacier its entire remaining load is let down upon that already accumulated. Thus were formed, beneath the great continental glaciers, vast expanses of unassorted or poorly sorted earthy material, called *till* or *boulder clay*. In regions of nonresistant bedrock and near the margins of the regions of former glaciation the till has accumulated to thicknesses of many feet or even several scores of feet. In regions of resistant bedrock and near

[1] R. F. Flint and H. G. Dorsey. Glaciation of Siberia. *Bull. Geol. Soc. Amer.*, Vol. 56, pp. 89-106, 1945.

the centers of glacial origin it is generally less abundant and is entirely lacking in some localities. In the latter regions the ice was less able to secure debris and, being less heavily burdened, was able to move most of the available material outward toward its margins. Specific glacial deposits are called *moraines*, and the till, because much of it was held in the bottom of the ice, is called the *ground moraine*, sometimes also the *till sheet*.

379. Where Glaciers Deposit. The ground moraine which was formed under the ice is only one of several forms of glacial deposit, or *glacial drift*. At places where ice advance was for a long time nearly balanced by the rate of melting, the edge of the ice remained almost stationary for years or scores of years. About these stagnant margins accumulated great ridges of drift, which, as a class, may be called *marginal moraines*. Those formed about the margin of the ice at its most advanced position are called *end moraines*, while similar ridges formed at times of pause or slight readvance during its stagnation and final wastage are called *recessional moraines*. Marginal moraines are comprised of drift that is in part shoved or plowed in front of the moving ice and in part fallen or washed out of its melting margin (Fig. 203).

There is much of the glacial load, however, which does not stop under the ice or upon the moraines about its margin. This material is carried beyond the ice margin by the streams of water that result from the melting of the ice. Like all stream-transported earth, it is sorted somewhat according to weight, the fine muds being carried farthest, and the coarser heavier materials being put down close in front of the ice. There are made by this process deposits of stream-sorted materials, such as gravel and sand, some of which extend away from the ice margin after the manner of river floodplains. The deposit of a glacial stream is classed generally as *glaciofluvial* rather than as glacial material. When these stream-sorted glaciofluvial deposits are arranged in floodplain form, they are known as a *valley train;* and when they are spread in broader fanlike deposits about the ice margin, materials of the same origin are called *outwash plain* (Fig. 211).

380. Glacial Disturbance of Drainage. The processes of glacial erosion and deposition both disturb the normal processes of stream development. Glacial erosion, unlike stream erosion, does not produce a uniform slope or gradient. Instead, glacially eroded surfaces exhibit numerous upgrade slopes in the direction of ice motion, rock basins, and ice-scoured hills, whose patterns of arrangement result from the accidents of the direction of ice flow, its erosive capacity, and inequalities in the resistance of the rock formations. In regions of glacial deposition also there is little of local plan or order in the thickness and arrangement of the drift. Consequently, the drainage of both ice-eroded and drift-covered regions appears without pattern, wandering, aimless, falling here over a ledge of rock or collecting there as lake or swamp in a depression (Fig. 210). Such stream patterns do not grow entirely as the result of headward erosion but come into existence with the uncovering of the surface at the disappearance of the glacier.

381. Newer and Older Drift. Among the glacial deposits of North America are striking contrasts as to apparent age. In the younger drift freshly scratched boulders, newly piled hills, and unfilled depressions indicate an origin in very recent geologic time. Other deposits, clearly glacial in nature, contain many weathered boulders, hills much subdued by rainwash, and depressions so generally filled that lakes and swamps are few. From these and other evidences it is known that the continent was invaded by ice sheets at least four times at intervals of many thousands of years, but all of them in relatively recent (Pleistocene) geologic time, beginning perhaps one million years ago and ending only some fifteen to twenty-five thousand years ago (Fig. 219; Appendix E).

The Gradational Processes of Waves and Currents

382. Where Land and Sea Meet. The oceans, seas, and lakes of the earth cover more

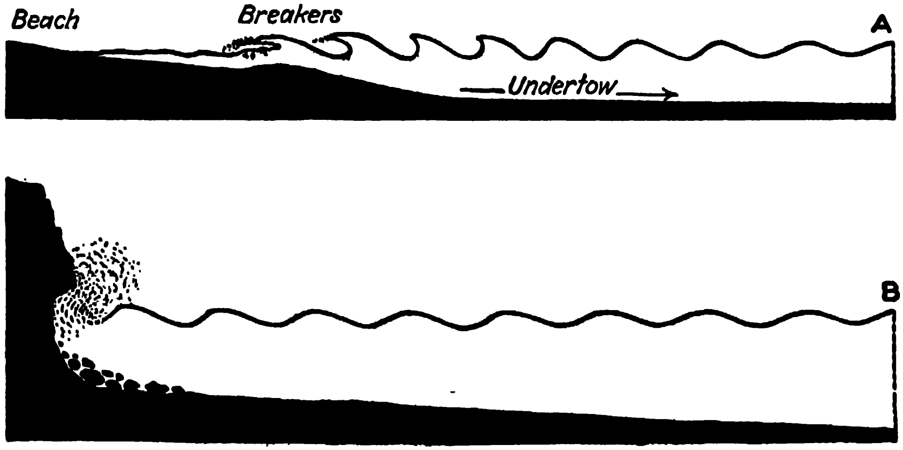

Fig. 156. Diagrams to illustrate wave forms and action in both shallow and deep shore waters. *A*, waves drag in shallow water, change form, topple, and break some distance from shore; *B*, in deep water they break directly on shore.

than 71 per cent of its surface and are important agents in the making and changing of landforms. Their work is accomplished by means of movements of the water, especially waves and currents. These are induced mainly by the wind and, to a lesser extent, by the tides and other causes. Although waves and currents are found in the open seas as well as in coastal waters they do not reach the bottoms of deep seas and so produce no change there. Their gradational work is restricted to the shallow sea margins with waters of less than about 600 ft. depth. Even in these ocean shallows the amount of wave work is small, and by far the greater part of it is performed along the coastal margins in waters of no more than a few feet or a few tens of feet in depth. The total areas subject to change by this force are, however, considerable, since the shorelines of all the lands have a combined length of many thousands of miles.

The work of waves and currents, like that of rivers and glaciers, has two phases: degradational and aggradational, or erosional and depositional.

383. How Waves and Currents Degrade Land. The greater part of marine erosion is accomplished by waves. Waves, most of which are caused by the wind, are undulatory motions of the water. In small waves the motion is confined to surface waters, but in great ones there is sufficient agitation to cause some churning of the bottom at considerable depths. This action aids in the removal of material from elevations on the shallow ocean bottoms. With the help of currents the material is greatly shifted to lower or more protected places, a process that results in a general leveling of the sea floor near the shore where the agitation of the water often extends to the bottom.

There is little forward motion of the water in the waves of the open sea. A wave is the motion of a shape, not of a mass. The wave form moves forward just as waves may be seen to run across a field of standing grain or may be sent along a shaken rope. However, as a wave enters shallow water a change comes over both its shape and its motion. The wave form shortens horizontally and increases in height. It drags on the bottom, inclines forward, eventually to topple, or *break*, with a motion that throws forward a considerable amount of water (Fig. 156). The water thrown forward by breaking waves rushes upon the shore only to lose its velocity and run back, under the pull of gravity, beneath other oncoming waves. The returning water is called the *undertow*, and it has sufficient force to be an important factor in erosion.

The erosive work of waves is accomplished both by the forward motion, or slap, of the water as the waves break and by the sand and rocks that they carry and use as tools. In either case the principal work is done where the waves break. On exposed coasts, where deep water lies immediately offshore, even great waves do

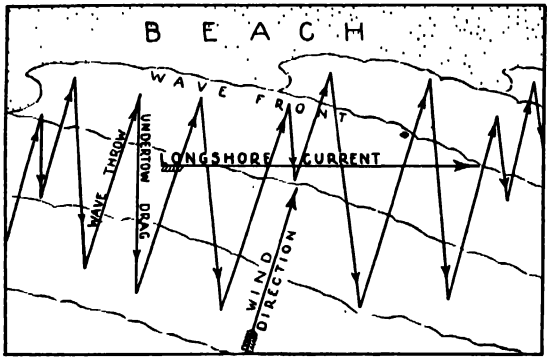

Fig. 157. A map diagram to illustrate the in-and-out path of a pebble under the combined forces of oblique waves, undertow, and longshore current.

not break until they reach the shoreline. There the force exerted by the sheer weight of the water in great waves is truly impressive. Blows of a ton or more per square foot are not uncommon. This is sufficient to dislodge and move about rock fragments of great weight. The effect of the undertow is to move the broken fragments away from the shore into deeper water where they are caught by oncoming waves and moved shoreward again. By this means waves are furnished with tools that greatly increase their erosional effectiveness. Sand, pebbles, and sometimes great boulders are hurled upon the shore, especially at the bases of exposed headlands. There they are thrown forward and rolled back in endless repetition, scratching and grinding against each other and the solid rock of the shore, accomplishing notable erosion. The general effect of wave erosion is to cut back coastal projections, decreasing the area of the land, straightening the coast, and developing, in the process, several characteristic coastal features such as wave-cut cliffs and marine benches (540).

When the direction of the wind is such that waves strike a shore obliquely the combined effects of the diagonal shoreward motion of the breaker and the offshore motion of the undertow is to cause both water and the wave-transported material to progress slowly, by angular, in-and-out paths, along the shore. Where the winds are prevailingly from one direction, there is set up by this means a continuous flow of water, or *longshore current*, which has much to do with the distribution and forms of coastal sediments (Fig. 157).

384. How Waves and Currents Aggrade. The products of wave erosion, together with sediments emptied into the sea by rivers, are shifted about by waves and currents but ultimately are deposited by them. Their tendency is to settle first in low places, aggrading them and leveling the sea floor. Because wave activity does not extend to great depths, the sediment, nearly all of which is land derived, does not spread far from shore. The coarsest is deposited first, and the finest is carried farthest out. This process results in a general assortment of shore deposits according to their sizes. Large boulders seldom are moved far from the places of their origin. Pebbles of comparable size are collected as deposits of shingle and beach gravel. Sands are more easily moved, cover vast expanses of shoreline, and extend out into waters of some depth. Beyond these, and also in protected shore waters, are collected the silts and muds that remain longer in suspension and are deposited in the quiet offshore waters of greater depth or in those of protected bays or coastal lagoons. In areas so situated that little mud is deposited there, lime is precipitated from solution and accumulates together with the limy and siliceous shells of small marine organisms.

Thus are originated the sands, muds, and limes which in many regions have been uplifted from shallow sea margins and have become the stratified sedimentary rocks of the continents. Changes of condition during the deposition of marine sediments, such as increase or decrease in depth of water or change in the supply of sediments, result in the sequent deposition upon one part of the sea floor of sediments of different kinds. For that reason it is usual to find undisturbed sedimentary rocks including sandstones, shales, and limestones, in any order of sequence, one above another.

385. Where Waves and Currents Aggrade. During the progress of coastal aggradation under the influence of waves and currents, the deposits of sediment alongshore assume a number of distinctive forms and modify coastal outlines.

These have some importance among the characteristics of coastal regions and greatly affect the manner of their human use. Although the features themselves are to be considered in other connections, it may be noted here that they are formed mainly in shallow water. The breaking of waves on shelving bottoms and the slacking of currents in the quiet waters of sheltered bays and in the lee of projecting coastal features all provide conditions under which sediments accumulate.

The Gradational Processes of the Wind

386. How the Wind Degrades. The wind is an important transporting agent. The air is never without dust in suspension, and winds of high velocity are capable of moving sand and even pebbles for some distance. Some of the materials carried by the wind are thrown into the air by volcanic explosions, but the greater part is obtained by the wind directly from the earth. This process of surface degradation, during which dust is whipped up by the wind and is transported from one place to another, is called *deflation*.

The process of deflation is least effective in regions where soil particles are moist and adherent or are protected by a covering of vegetation. It is most effective in regions of aridity and scanty vegetation such as the deserts, exposed areas of beach sand, the recently dried muds of river flats, areas of newly deposited glacial drift, or bare plowed fields. Over large areas of dry desert all the fine surface material has been removed by the wind, leaving a *desert pavement* of the heavier gravels and pebbles (Fig. 231).

The process of deflation is to some extent aided by wind abrasion. The wind-transported particles scratch, polish, and reduce each other and to some extent the solid rock, producing fine particles which in their turn are removed from the region.

387. How Wind Aggrades. Wind, like streams and waves, deposits its load of coarse material promptly but is able to carry fine particles farther and distribute them more widely. Loose sands are supplied in abundance by the weathering of desert rocks or by wave deposition on shorelines. Where the sands are not anchored by vegetation or moisture, they are whipped up by wind and drifted into the sheltered lee of some obstruction, where the decrease in wind velocity permits some to be deposited. Thus is begun the growth of a *sand dune* which, by its own height, provides further shelter and promotes its own growth. The growth of a dune often is accompanied or followed by a change of its location. A film of sand is stripped from the windward slope of the dune and deposited in the lee of the crest. By continuous subtraction from the windward and addition to the leeward the dune moves slowly, but seldom far, from the source of sand supply (Fig. 248).

The dust supplied by rock weathering and abrasion in dry regions is drifted by prevailing winds over wide expanses to the leeward. There probably is a considerable quantity of windborne dust in most soils, but in regions immediately to the leeward of arid lands, where deflation is active, it is particularly abundant and may attain great thickness. Considerable accumulations of wind-deposited dust are called *loess* (461). In northern China there are extensive deposits of loess that in places reach more than 100 ft. in thickness. In central Europe and central United States also are widespread loess deposits which may have originated in part from the dried and wind-blown muds of glacially enlarged drainageways during the glacial period.

SECTION D: *Landforms*

388. The foregoing discussion of earth materials and processes leads naturally to a consideration of the earth features resulting from the operations of those processes upon earth materials. This, it may be repeated, is a matter of immediate concern to the student of geography. The purpose of this section of the book is to describe and depict some of the significant and recurring surface features of the land, to sketch their patterns and locate regions in which they are found, and to indicate something of their relative degrees of human utility. The principal groups of landforms to be considered, as distinguished by their several characteristic features and degrees of relative relief, are (*a*) plains, (*b*) plateaus, (*c*) hill lands, and (*d*) mountains.

Within each of the above principal groups there are surface features of a smaller order of size. These are the hills and valleys, the broad uplands and flat lowlands, and the many other landforms with which the daily affairs of men are concerned. Analytical study of the variety of features characteristic of any one of the major landform groups shows (*a*) that they are capable of separation into types upon the basis of their shapes and manner of arrangement and (*b*) that each type results from the interaction of earth processes in a region with given conditions as to climate and as to kind and structure of rock. It is the purpose of the chapters that follow in Sec. D of this book to describe the groups of landforms and their distinctive types of features and to indicate the manner of their association. By constant reference to the brief discussions of materials and processes in Sec. C the likenesses or differences between features may be sharpened and made clearer.

Because of the relationships between some classes of land-surface features and the kinds and structures of the rocks which underlie them, the student is urged to make frequent comparison of Plate IV, Lithic Regions, and Plate V, Landform Regions, in the back of this book. Using them, he may associate the dominant landforms of an area with the general character of the rocks in the same area. The map scale of these plates being small, it is not always possible to determine the associations existing in small areas, but those characteristic of the large or general areas referred to in the text may be seen, and they will be found helpful.

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See also the list of references included under Section C.

CHAPTER 14: *Plains of Stream Degradation*

General Considerations Relative to Plains

389. How Plains May Be Distinguished. It is recognized commonly that, of the four principal classes of landforms, plains have the greatest areal extent and general habitability and that most of the world's great plains are situated in their respective continents so that they slope toward bordering seas without notable interruptions to the continuity of their surfaces. However, an acceptable basis for definitely distinguishing plains from each of the other major subdivisions is not easy to arrive at because plains lands, in many places, grade almost without interruption into hill lands or plateaus. One significant difference among the four classes of features is found in their respective degrees of roughness. This may be measured in terms of *local relief, i.e.*, the difference between the elevation of the highest point and that of the lowest point within a limited area (392). *The term plain is here applied to all land that is relatively low with respect to sea level and has a local relief of less than about* 500 *ft.*

All plains lands are by no means alike in their elevations above sea level. Some broad plains reach altitudes of several hundreds of feet, while others are depressed and stand, behind barrier rims, at elevations somewhat lower than sea level. There are other differences between plains also. Some are very flat, while others are rolling or even rough, within the limits of their general relief. However, in spite of their great variability, plains are much the most habitable of the major landform subdivisions of the continents. Because of their low degree of local relief they have, generally, low angles of slope. They are, therefore, easily traversed by routes of transportation, and the surfaces of such as are by conditions of climate and drainage suited to crops largely are capable of tillage. In some parts of the American Corn Belt as much as 70 to 80 per cent of the total land area is plowed and planted to crops. That leaves but 20 to 30 per cent to be devoted to pasture, wood lots, farm buildings, roads, towns, and all other uses. This could not possibly be true of plateaus, hill regions, or mountains. Plains have, therefore, as compared with plateaus, hill lands, and mountains, large food-producing capacity, and it is not surprising that they contain the principal centers of world population.

390. General Distribution of the World's Plains. A study of the location and distribution of the world's great plains (Plate V) will reveal the significant fact that much of the greater part of them are situated in their respective continents in a manner such that they are tributary, both physically and commercially, to the Atlantic Ocean. Some are directly so while others, such as the plains of northern Asia and northwestern Canada, are only indirectly tributary to the Atlantic. The Siberian plains, although they are, in large part, nearer to the Pacific Ocean, are separated from it by considerable mountain or plateau barriers. Only the smaller plains of southern and eastern Asia, Australasia, and western America face upon the Pacific Ocean. This condition is to be expected, in view of the fact that the borders of the Pacific comprise the most extended world region of young and growing mountains.

391. The details of plains relief include uplands and lowlands, ridges and valleys, hills and hollows, all within local ranges of eleva-

tion of 500 ft. or less. In some respects they are like the similar features found in plateaus, hill lands, and mountains except that they have less relief and much greater areal extent. However, there are so many essential differences between the characteristic features of plains and those of the lands of greater relief that the former are worthy of separate and extended consideration.

A survey of the plains regions of the world from the viewpoint of their smaller relief features indicates that there are extensive areas in which essentially the same combination or association of features is found throughout. Any one of these areas of physiographic unity is likely to be a region of uniform rock composition and tectonic history which has been acted upon by the same gradational agents to about the same degree. In other words, the entire area, large or small, is of similar origin and has had a similar history. Moreover, these combinations or associations of features are in some degree repeating, plains of similar origin and features being found in different parts of the world. For example, plains of one type may be found in Ontario and Scandinavia, of another type in eastern Wisconsin and northern Germany, and of still another in Kansas and Argentina. Because of differences in the shapes and arrangements of their features, plains regions of different origins and histories do not look alike. For that reason it becomes necessary to classify them in order that they may more adequately be described.

392. Classes of Great Plains. For the purpose of convenient description the major plains lands of the earth may be grouped in several different ways. The basis of the grouping will, of course, depend upon the purpose for which it is made. The following are possible groupings, each of which has its own merits from the standpoint of regional geography: (*a*) Plains may be classified in accordance with their climatic situation. There are, for example, humid tropical plains, arid tropical plains, and subarctic plains. Such a grouping of the plains of the world recognizes an important element, the climatic one, concerned in the development of the landforms of plains but does not thereby give a complete background for the understanding of all the landforms commonly found in plains of each of the climatic regions. (*b*) Plains are sometimes classified, in accordance with their situations in their respective continents, as coastal plains and interior plains. (*c*) They may be classified also in accordance with their prevalent conditions of geological composition and rock structure. Upon this basis one may recognize plains of horizontal sedimentary rock, peneplains of ancient crystalline rock, plains of glacial deposition, and others. (*d*) Highly important, from the geographical point of view, is the comparative roughness of plains. The element of roughness is significant because it is indicative of various aspects of the human utility of plains, such as the freedom of drainage, the rapidity of soil erosion, or the ease of tillage. Moreover, it is measurable with some accuracy in terms of local difference in elevation, or local relief.

The comparative roughness or local relief of landforms may be indicated by means of the maximum difference in elevation found within any chosen area of restricted size. A study of local relief in the United States, upon which the following classes were based, employed for the purpose the area of a quadrangle of $7\frac{1}{2}'$ of latitude and longitude, including horizontal distances not exceeding 10 miles. Upon this basis one may recognize (*a*) *flat plains*, having a local relief of less than 50 ft.; (*b*) *undulating plains*, having a local relief of 50 to 150 ft.; (*c*) *rolling plains*, having a local relief of 150 to 300 ft.; and (*d*) *rough dissected plains*, having a local relief of 300 to 500 ft.

Each of the above broadly descriptive classifications is based upon conditions which need to be understood before the habitat significance of a plains region and the details of landform developed upon it can be appreciated fully. A classification involving all the elements indicated above certainly would be more explicit but also more complicated and less inclusive. Under such a classification one might list, for example, a gently undulating coastal plain of unconsolidated, horizontal, marine sediments

Fig. 159. Flat but well-drained coastal plain in Texas.

elevations is slight, there are large areas of both river-bottom and upland swamps. The upland swamps, locally called *pocosins*, or *bays*, are situated upon the divides or interfluves and are exceedingly numerous (Fig. 160). Although they generally are of small size, a few of them are of notable extent. The largest are the Everglades of Florida; the Okefenokee Swamp, located astride the Florida-Georgia boundary; and the Dismal Swamp of North Carolina and Virginia. The swamps of the Atlantic and Gulf Coastal Plains, both upland and river-bottom, are so numerous and so large that, altogether, they comprise nearly two-thirds of all the ill-drained lands of the United States. Other coastal lowlands also are characterized by the presence of large swamps. Such is the nature of the broad coastal flats of eastern Nicaragua and the eastern coast of South Africa.

On the Arctic fringes of Alaska and of the Soviet Union, both east and west of the Ural Mountains, are newly emerged plains. In them the features of poor drainage, common to plains of this class, are accentuated by permanent frost in the ground.

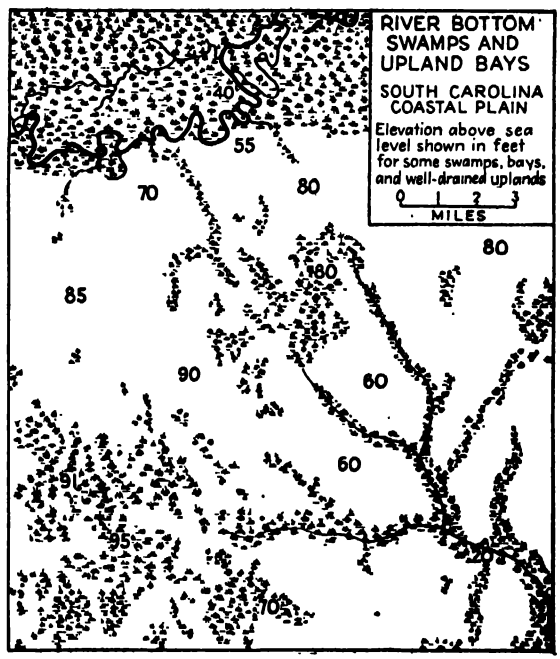


Fig. 160. The interfluves in this area have not been entirely reached and drained by the stream tributaries. Compare the elevations of different swamps.

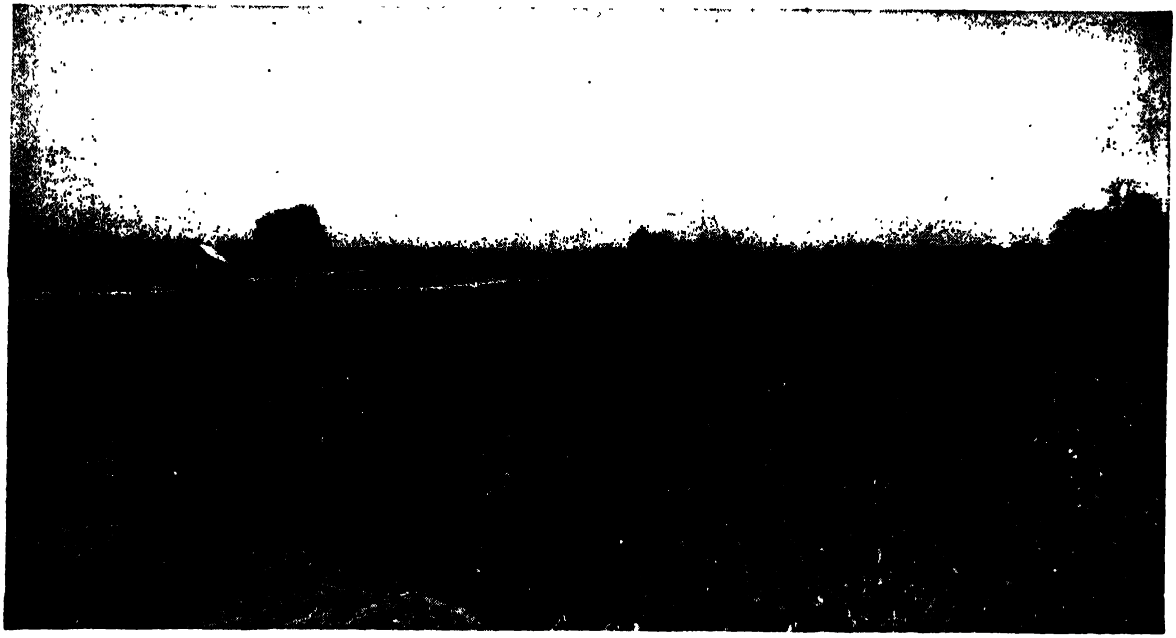


Fig. 161. The undulating surface of the inner coastal plain in central Georgia. The broad, low interfluve is cultivated, but the slopes and bottoms of the creek valleys are wooded.

396. Stream-eroded Plains, Young and Old. Although plains are lands of low relief, even they pass through the successive stages of erosional development from youth to old age. This is true of coastal plains no less than of others. The features of such plains may show the effects of stream erosion on rocks of several different types. These may be (*a*) flat-lying or very thick beds of sedimentary rock which are uniform over large areas, (*b*) inclined sedimentary strata or such as have been faulted, and (*c*) ancient crystalline rocks of great structural complexity. As the erosion of the plain proceeds, the developing landforms reflect the local peculiarities of the rock structure, the climatic conditions, and the stage of completion to which the streams have carried their work.

In regions where stream erosion is the principal gradational process, some plains are smooth because they are young, and the erosional process has barely begun; some are smooth because they are old, and erosion has proceeded as far as it can; and a few are smooth because they have been stripped down to the smooth surface of some resistant and widespread rock formation. In general, the roughness of a plain, that is, the thoroughness and depth of its stream dissection, depends upon the elevation of the plain with respect to the local baselevel and upon the stage to which the erosional cycle has advanced. Therefore, plains of whatever rock structure may be classified also, according to the stage of their erosional development, as young, mature, or old (371). A newly emerged coastal plain is likely to be young. It may be eroded, but it cannot be very rough (Fig. 161) because its baselevel is so close beneath the original surface that even mature dissection by streams cannot produce deep valleys. Some elevated interior plains are undissected, flat, and very young, but others, where erosion is well advanced, are so rough that they reach the arbitrary limit of 500 ft. of local relief set for plains and approach hill country in appearance. Plains that have been reduced to old age by stream erosion usually have undulating surfaces.

397. *Young stream-eroded plains* are characterized by broad, smooth interfluves which are traversed at intervals by narrow, steep-walled valleys. In some young plains the major valleys have reached grade and have developed broad bottoms in which the streams meander before

later stages of the process are so slow, that few if any of the peneplains of crystalline rock ever were perfectly finished. Unreduced portions in the form of erosion remnants, or *monadnocks*, in some places are to be found standing in bold relief above the general level of their surfaces as reminders of the greater heights at which the regions once stood. Moreover, although many peneplains are known, none is now found that is either very low or very flat. It may be supposed that before the slow process was finished it was interrupted by diastrophic change which elevated the land sufficiently to steepen the gradients of the streams and permit them to erode the peneplains into undulating or rolling plains whose uplands lie at the general level of the ancient surface and above which the occasional monadnocks rise still higher. Some peneplains have been so greatly elevated that portions of their former flattish surfaces are now found among the heights of hill regions or mountains.

401. Lowland Peneplains. Some ancient peneplains, although somewhat re-eroded, still are so comparatively level that they may be classed as plains. The Appalachian Piedmont of the United States and parts of the Amazonian plain (Plates IV and V) may be cited as examples of former crystalline peneplains whose present surfaces have developed under conditions of warm and humid climate. They are characterized by rolling surfaces, occasional monadnocks, and deep accumulations of weathered and leached regolith. On the Appalachian Piedmont the remnants of the ancient peneplain still are broad, although newer valleys have been carved into its surface. The uplands are the sites of the principal cultural forms and are given over largely to farming which, in many localities, has resulted in a rapid erosion of the soil. In this region also some of the monadnocks are of more than local importance. Such are Stone Mountain, near Atlanta, Ga., King's Mountain, famed as a battleground in the American Revolution, Spencer Mountain, North Carolina (Fig. 165), and others.

There are in some regions of arid climate areas of stream-eroded piedmont plain (pediments) the beveled surfaces of which are so closely associated with desert phenomena that comment upon them will be reserved for discus-

Fig. 164. Rough, dissected plain in southwestern Wisconsin. The local relief in this region averages about 500 ft., but in some localities it exceeds that figure and the surface is truly hilly. (*Wisconsin Geological Survey photograph.*)

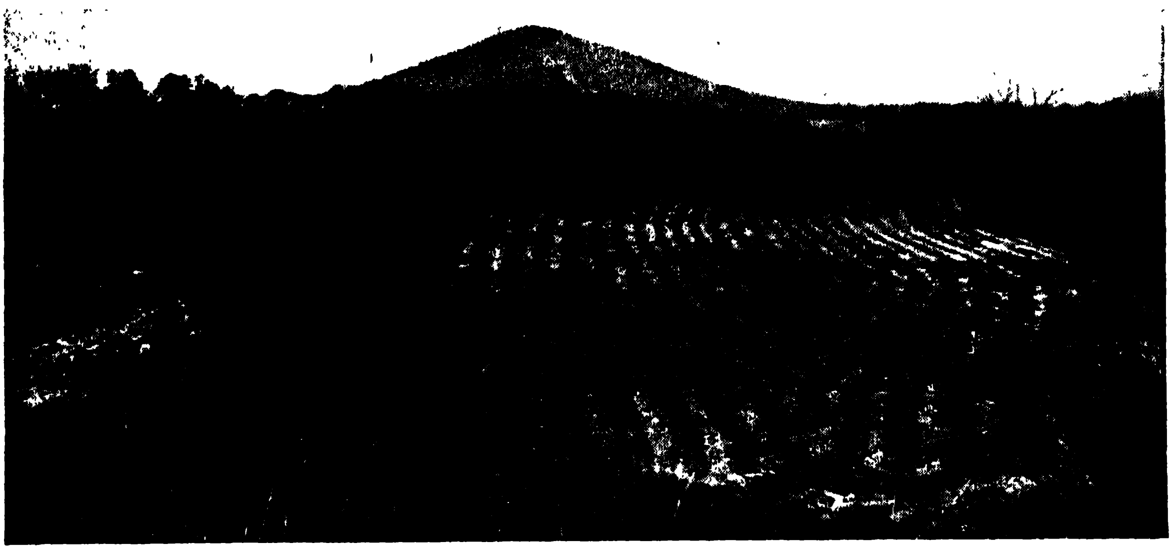


Fig. 165. Spencer Mountain, a monadnock on the partially re-eroded peneplain of the Appalachian Piedmont, near Gastonia, N.C.

sion with the features developed under arid climates (453). Also there are extensive areas of crystalline peneplain whose present details of surface have been produced by agencies other than stream erosion. Such are the glaciated peneplains of Canada, northeastern United States, Sweden, and Finland (434). These, too, will be considered in other connections.

402. Cuestaform Coastal Plains. In the preceding discussion of coastal plains (394 and 395) it has been assumed that the processes of stream erosion and their resultant land-surface features have been accomplished in regions where the underlying strata are essentially horizontal or of such great thickness that a single stratum is exposed over a large area. However, the strata underlying some coastal plains are neither horizontal nor very thick. The effect of erosion upon them is to produce features the forms and patterns of which are distinctive.

Upon the inner and more elevated portion of the Atlantic and Gulf Coastal Plains of the United States stream erosion of the young sediments has produced a notable arrangement of features. Here are exposed, one after another, the landward edges of the lower and older members of the whole series of gently inclined coastal-plain strata (Fig. 166). Erosion has beveled their surfaces and has exposed them so that they appear as alternate bands or belts several miles wide and many miles long which trend, in a general way, parallel with the coast. The relation of these rock strata to each other is like that of several sheets of paper piled so that, beginning at the bottommost, each protrudes a little distance beyond the one above it. If the papers were of different colors the exposure of each would produce a band or belt of color. A region in which the rock strata are so exposed is known as a *belted coastal plain*. It has an undulating surface and, because it is somewhat higher and has slightly steeper stream gradients, it has not the great areas of swampland that are found on its newly emerged seaward margin just previously described.

Because the belts are made up of strata of lime, clay, and sand, they differ in their features of soil, drainage, and relief. The sediments, although geologically young, have been somewhat con-

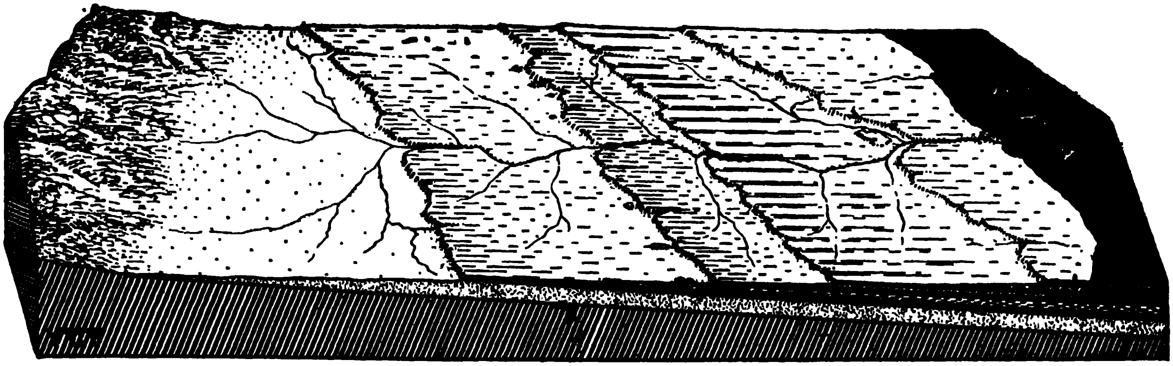


Fig. 166. A diagram to illustrate the cuestaform ridges, intervening lowlands, and related rock structure of a belted coastal plain. The rock strata shown in solid black are indicated as having superior resistance to erosion.

solidated by pressure and cemented by minerals deposited from solution. They are inclined toward the coast at low angles but not so low as that of the slope of the plain in the same direction. Streams have carved more readily into the less resistant of these formations, leaving the exposed edges of the more resistant, often sandstones, standing in relief. Owing to the attitudes of the rocks, long low ridges are thus produced alternating with broad lowlands. The ridges, under humid climate, have been carved into belts of hills. They have a relief of 100 to 200 ft. above the lowlands, trend roughly parallel to the coast, are asymmetrical, and usually present steeper faces toward the inland direction and more gentle slopes to seaward The relation of the alternating ridges and lowlands above described to each other and the manner of their erosion by streams will become apparent from a study of Fig. 166. Ridges of this kind are called *cuestas.* Their steeper inland faces are called *escarpments;* their gentler slopes are called *dip slopes.* Figure 167 shows the conspicuous ridges of the Alabama Coastal Plain, together with the pattern of the streams now adjusted to the rock structures of the region. The valleys between the ridges are called lo lands, and the innermost valley, which is adjacent to the older land, is called the *inner lowland.* Extensive plains that include a series of cuesta ridges and intervening lowlands may be spoken of as *cuestaform plains.* It happens that the broad inner lowlands on both the Alabama and Texas Coastal Plains are eroded in chalky limestones which have given rise to soils of great productivity (642). These lowlands, which are called the *Alabama Black Belt* and the *Texas Black Prairies,* have become major centers of population and agricultural wealth (Fig. 168).

403. Stream-eroded Plains in Older Sedimentary Rocks. Many plains of gently inclined sedimentary rock, located well to the interiors of continents, show features somewhat like those of the belted coastal plain. These have been developed by stream erosion but are different from those of coastal plains because the ancient strata have been somewhat changed, by diastrophism and the cementing action of deposition by ground water, both as to their

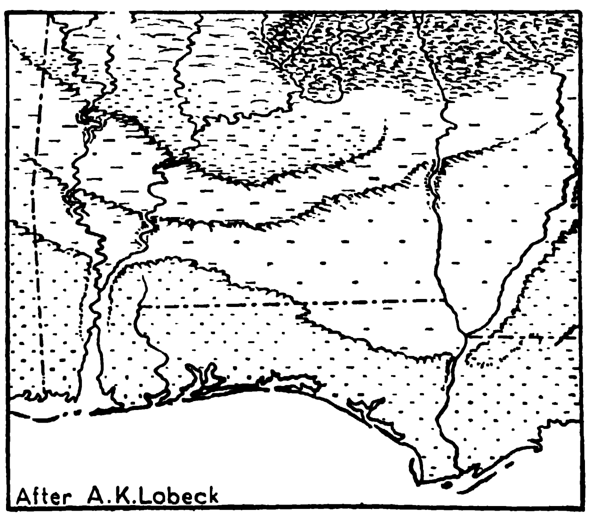


Fig. 167. The principal cuestaform ridges of the Alabama Coastal Plain. The escarpments face generally northward.

Fig. 168. White Rock escarpment, the west-facing front of a low cuestaform ridge on the Texas Coastal Plain near Dallas.

positions and as to their resistance to erosion. It is probable that erosion, in these older plains, since their emergence as coastal plains, has removed scores or even hundreds of feet of rock that formerly lay above the present surfaces. During this slow process the original surface of the coastal plain, with its ill-drained depressions, has completely disappeared, and the streams have adjusted themselves to the conditions of structure and hardness in the different rocks. These older and better consolidated sediments have existed through long periods of geologic history and have, in some places, been involved in minor tectonic movements which have resulted in changes in the inclination of the strata or in the formation of broad structural arches and basins. Stream carving in the rocks of which they are made has produced several distinctive kinds of plains features.

404. Cuestaform Interior Plains. The development of interior plains by differential stream erosion on gently inclined, older sediments is not uncommon. One special result of this process is the formation of cuestas and lowlands like those of belted coastal plains, although some are of larger size. Of that origin are the plains of much of the upper Mississippi Basin. In them the escarpments of some of the cuestas present features of bold relief, the height and irregularity of their crests depending much upon the thickness and resistance of the rock formations to which they are due. In general, however, the ridges of cuestaform plains are not bold features but are dissected into belts of hills whose heights are not great when compared with the widths of the intervening lowlands.

405. *Examples of Cuestaform Plains.* In southeastern England the Lincoln Wolds, the Cotswold Hills, the several Downs, and other ridges are cuestas formed by the differential erosion of inclined rock strata. Mainly the ridge-making rocks are porous chalky limestones which have resisted erosion by their absorptiveness. In the Mississippi Basin various sedimentary strata incline gently away from the old land of the Lake Superior Highland and disappear beneath the newer sediments of the Gulf Coastal Plain. The outcropping edges of the more resistant of them, mainly sandy or cherty limestones and dolomites, form a series of cuesta ridges (336; Fig. 169). One of these is the Military Ridge of southwestern Wisconsin. Another, and a most

persistent one, is the Niagara cuesta, an outcrop of a hard magnesian limestone. It traverses northern Illinois, eastern Wisconsin, upper Michigan, and peninsular Ontario and finally dies out in western New York. Its projecting crest is the cause of the Door Peninsula of Wisconsin, the Manitoulin Islands, the Bruce Peninsula of Ontario, and the escarpment that gives rise to Niagara Falls. The dip slopes and intervening lowlands of these cuestaform ridges are undulating farm lands, although in central Wisconsin the inner lowland is a broad and relatively infertile sand plain resting upon an underlying sandstone. Minor features upon these plains include groups of hills which are remnants of the cuesta escarpments, detached and left isolated by differential weathering and erosion. Such hills, which lie out beyond the margin of the main body of the rock of which they are composed, are called *outliers*. They are exemplified by the Mounds of southern Wisconsin. The same processes have given some of these outlying hills bold or even fantastic and castellated forms.

406. Plains of Concentric Ridges and Lowlands. In the long histories of the older sedimentary rocks have occurred minor changes of level which have resulted in widespread and gentle warping of the rocks. Some such are expressed in various of the curves of the cuesta ridges shown in Fig. 169. Others resulted in low broad structural arches or domes or equally broad structural basins. The latter include several rock strata, some of considerable resistance and others easily eroded, nested together like a pile of shallow saucers of decreasing size. The subsequent differential erosion of a structural basin produces a series of roughly concentric lowlands and cuestas with *out-facing* escarpments. The Paris Basin of France is a notable example of a plain of this class (Fig. 170). Its five or six low cuestaform ridges have been partially dissected by streams and stand as concentric but broken ridges upon a fertile plain. The shapes, heights, and arrangements of these cuesta ridges have played important parts in the appearance of the plain, its agricultural uses, the pattern of its avenues of transportation,

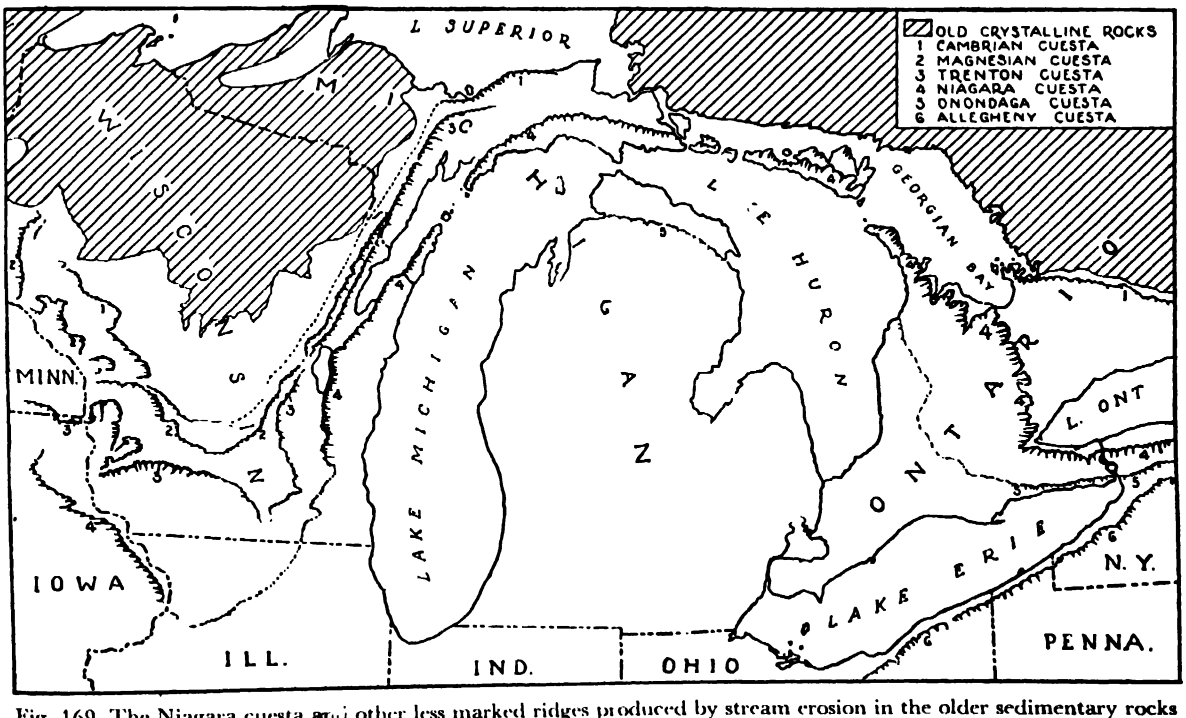


Fig. 169. The Niagara cuesta and other less marked ridges produced by stream erosion in the older sedimentary rocks of the Great Lakes region. Parts of some of the ridges are deeply covered by glacial drift, and their approximate positions are shown by broken lines.

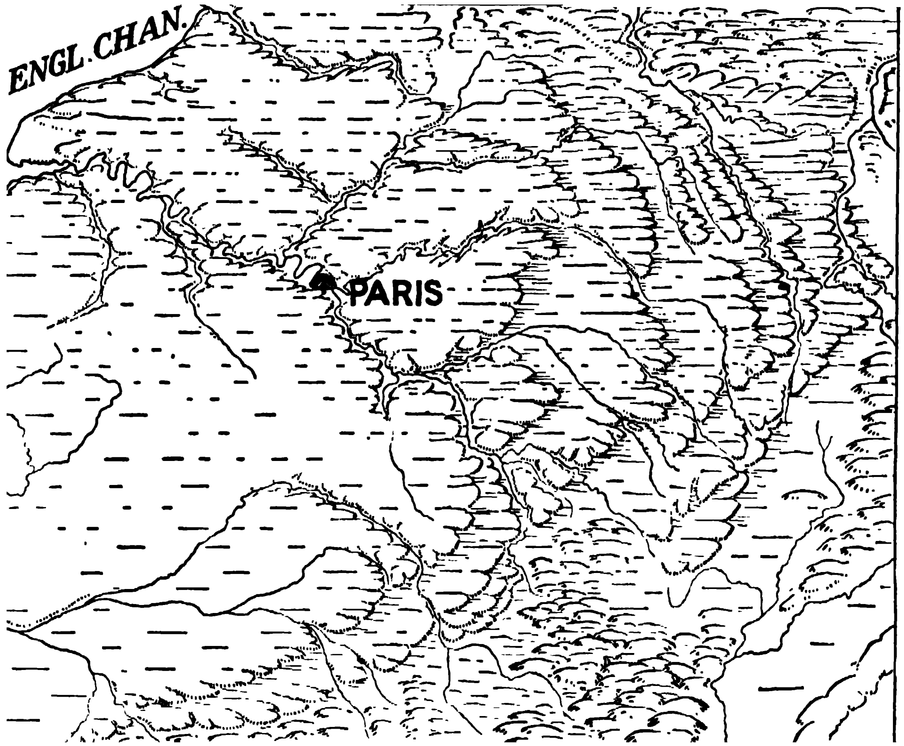


Fig. 170. The principal cuestaform ridges and out-facing escarpments of the Paris Basin.

Fig. 171. A north-south cross section through the outskirts of London showing the surface features and rock structures of the London Basin and The Weald. The section is 100 miles long, and its vertical scale is several times greater than the horizontal.

and the military defense of Paris, which is its natural focus. The London Basin is a similar, though somewhat elongated, structure which is traversed on its major axis by the Thames River.

Structural arches or domes, when subsequently their tops are attacked and removed by weathering and erosion, also produce concentric lowlands and cuestaform ridges but with *in-facing* escarpments. In England, for example, the south flank of the London Basin forms the north flank of an arch, the chalk cuestas of which are called the North Downs and the South Downs. Their escarpments face in upon the sands and clays of a rolling plain called The Weald (Fig. 171).

407. *Important American Plains of Concentric Features.* In the United States there are several notable examples of plains formed by the erosion of structural arches. The most important are those developed by the erosion of a long low arch which extends from southwestern Ohio to northern Alabama. Upon it are two oval cuestaform plains. These are the Bluegrass Region of Kentucky and the Nashville Basin of Tennessee. Each is about the size of the state of Connecticut. The upper formations of the arch primarily are

CHAPTER 15: *Plains of Stream Aggradation*

410. Alluvial Plains. Alluvium may be thought of as weathered and eroded material which has been halted in stream transit between higher lands and the sea. Attention has been directed previously to the nature of alluvial deposits and also to the manner and some of the characteristic places of their deposition (372). It may be emphasized now that, with minor exceptions, alluvium is deposited in the form of plains, and usually in flat plains, where it is spread out and awaits a future removal and the continuance of its transportation. In terms of the length of geologic time, alluvial plains are temporary structures. Some, indeed, are of very recent origin; their accumulation still is in progress, and their surface forms record the manner of their upbuilding and certain of the incidents in the process. Others are vastly older; the details of the manner of their construction and incidents in the process are lost; and their surfaces are characterized rather by features that mark stages in the progress of their destruction. These are distinguished by the term *older alluvium*. The details of surface form in four principal classes of alluvial plains may be considered. These are (*a*) delta plains, (*b*) flood plains, (*c*) piedmont alluvial plains, and (*d*) plains of older alluvium.

Delta Plains

411. The Great Delta Plains. Delta plains are the surfaces of newly built-up accumulations of river sediment which is deposited at the mouths of streams upon their entry into bodies of quiet water. Not all great streams have deltas, but all great deltas are the deposits of large streams. Some of the most extensive delta plains may readily be discovered on the maps of a student atlas. They are the delta of the Nile, from which all such deposits take their name (its triangular central portion resembles in shape the letter Δ of the Greek alphabet), and the deltas of the Rhone, Po, Rhine, Volga, Indus, Ganges, Irrawaddy, Hwang, Orinoco, Colorado, and Mississippi (Fig. 177). There are many more delta plains of almost equal size, but less well known, such as those which fringe the east coast of peninsular India. Of small deltas there are thousands.

412. The Delta Outline. The process of delta building, previously noted (373), is the

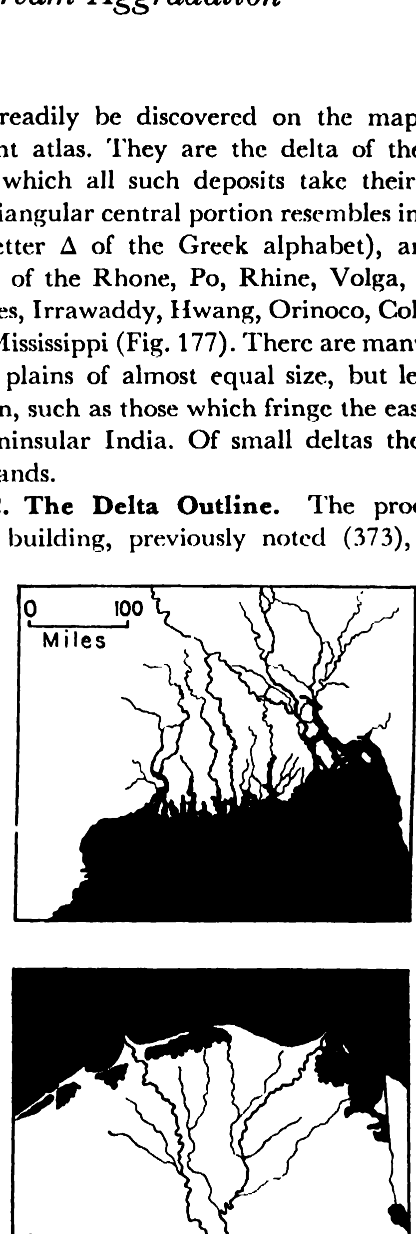


Fig. 177. Delta outlines and distributaries.

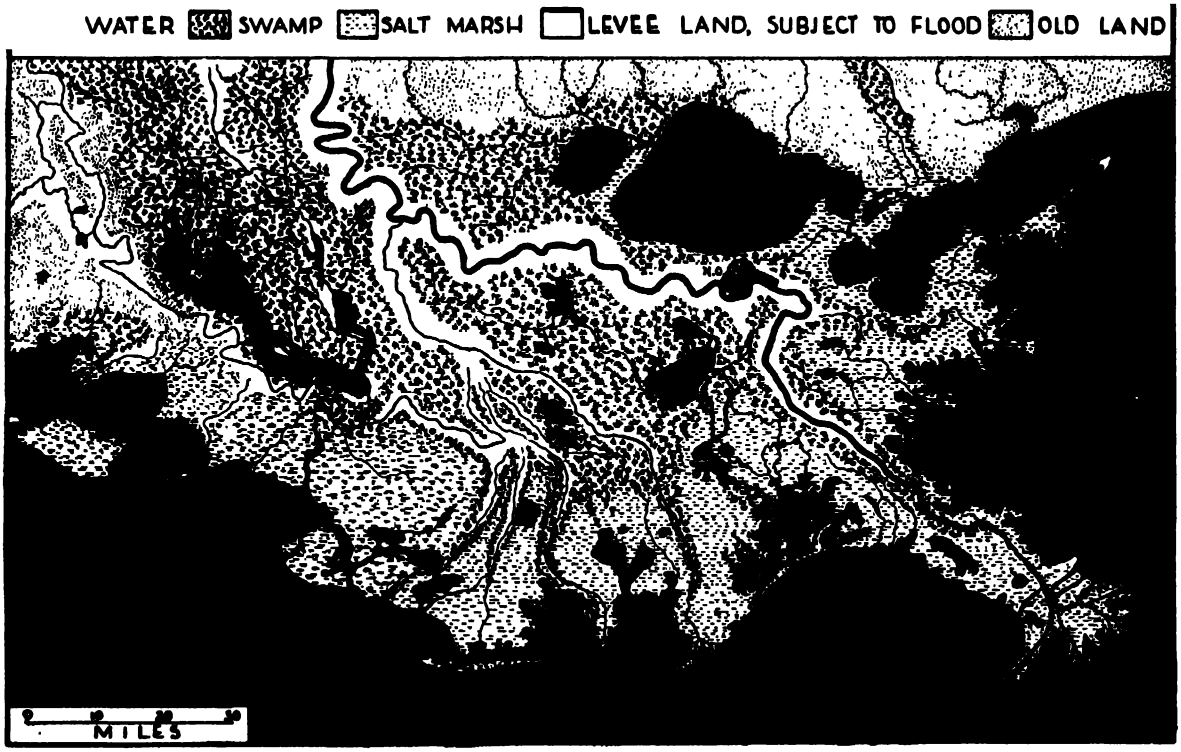


Fig. 178. The Mississippi River Delta has fringing areas of salt-marsh grass and reeds, belts of wooded swamp, and strips of tilled levee lands. Note that the levee lands grow narrow downstream and disappear.

cause of some peculiarities of delta shape and delta surface. The normal growth of the delta through the seaward extension of the distributary channels and their levees causes some deltas to present to the sea somewhat digitate (fingerlike) outlines. This feature is pronounced in the case of the Mississippi Delta (Fig. 178). It may be seen also on maps of the Rhone, Volga, and Nile deltas, but it is hardly noticeable on many others, including the delta of the Hwang. The manner of delta formation by addition to both the surface and the margin is responsible not only for the shape of the delta margin and its surface features but also for a great deal of the trouble and labor that are the lot of most delta inhabitants.

413. The Delta Surface. Although it is true that delta plains are very flat, since they generally have local relief of much less than 50 ft., they are not without significant differences in elevation. The seaward margin of the delta is lowest. There is the newest formed portion of the surface which continues out beneath the sea a little distance. Films of the finest mud are added to the seaward margin when the delta surface is flooded by the river, and silt and sand are thrown up there by the deposition of waves and currents. This seaward margin is built up so slowly and is so flat that, on large deltas, vast areas of the coastal fringe are little above salt water, and beyond the shoreline the coastal waters are exceedingly shallow except near the mouths of the principal distributaries. Along the delta border are marshy islands of new sediment, and it is traversed by a network of shallow and sluggish channels (Fig. 178). The upstream portion of the delta is highest, and it grows in height as the delta increases in age and extends in area. As the distributary channels lengthen by building seaward, the stream gradient is thereby flattened, causing a decrease in stream velocity. This in turn causes the stream to drop sediment in its own channel and to overflow its banks and deposit material upon

the delta surface. Flooding is repeated, and the surface is built up until a uniform gradient is maintained (Fig. 186). However, the difference in surface elevation is not great even on large deltas. The highest portions of the upper delta of the Mississippi, which lie nearly 200 miles from the river mouth, are only about 40 ft. higher than the delta margin.

The features of greatest relief upon the delta surface are its *natural levees* (373). These are low and broad ridges of alluvium which border the stream channels on either side (Fig. 179). They are found along the main stream of the delta, along its distributary channels, and also along the smaller independent streams which traverse the surfaces of large deltas. They are highest near the banks of the stream that builds them but, at least on the Mississippi Delta, they rise no more than 15 or 20 ft. above the adjacent delta surface. They are both higher and broader on the older upstream portion of a delta than near its newer seaward margin. From their crests they slope away from the stream with surfaces so gently inclined that, to the eye, they appear perfectly flat. However, drainage detects the difference, and, while the higher parts of the levees along the stream banks are generally well drained, their lower portions which slope away from the stream end in fringing swamps. The width of the great upper delta levees of the Mississippi, between river bank and swampland, commonly is 1 to 2 miles on either side of the river. The levees of the great river near its mouth and also of the smaller delta streams may be only a few yards wide, and in the salt marshes of the seaward fringe no levees may be yet developed (Fig. 180). It is characteristic of the levees of delta streams and distributary channels that they become lower and narrower downstream until they taper to points in the coastal marshes and there disappear (Fig. 178). Some of the lesser streams and bayous of the Mississippi Delta are bordered by levees much too high and wide to have been deposited by them.

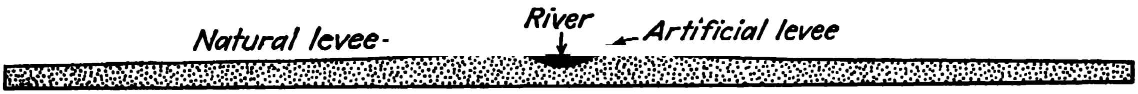


Fig. 179. A diagram showing the transverse profiles of natural and artificial levees. Vertical scale much exaggerated.


Fig. 180. Narrow natural levees parallel this small distributary bayou on the Mississippi Delta. The road, somewhat built up, occupies the crest of the levee. Another road parallels it on the other side of the bayou. The houses stand in the edge of the swamp and each has a motor boat or houseboat.

Fig. 181. High water on the lower Mississippi floodplain. The artificial levee is the only land remaining unsubmerged. The main channel of the river is seen in the far distance. The locations of several natural levees associated with minor channels are indicated by the belts of submerged woodlands and the site of the town. (*Official photograph, U.S. Army Air Corps.*)

These are known to have been made long ago by the great river itself, and they mark former positions of the Mississippi which it later abandoned by switching to other channels, including the present one.

Because the levees are the highest and best drained portions of the delta surface, they are the principal sites of human settlement. Houses and towns are found upon them, and roads and railways tend to follow them and to parallel the streams. Farms occupy the gently sloping surfaces and extend away from the river toward the lower swamplands. For protection against stream overflow artificial levees are, in some places, built near the stream upon the top of the natural levees. In times of high water on the Mississippi Delta the river surface may rise nearly to the top of the artificial levees or even overflow them. At such times it stands several feet higher than the roads and farms on the natural levees behind them and many feet above the swamps beyond. A break in the artificial levees at that time permits the flooding of a large part of the delta surface, and water may completely submerge the smaller levees of the lesser streams or even the great levees themselves (Fig. 181). On some great deltas, such as that of the Ganges River, no artificial levees have been built, and both the delta swamps and the natural levees are regularly flooded in the rainy season. There the inhabitants have built compact mounds of earth on which are located their houses and village settlements barely above the reach of high water.

414. Delta Drainage. The low flatness of the delta surface and the fact that its streams

Fig. 182. Broad marshes and shallow channels on the seaward margin of the Mississippi Delta. The distant row of trees occupies the remnant of a levee which borders an abandoned distributary channel.

flow down the middle of broad levee ridges at elevations slightly higher than the average surface of the plain create a difficult problem in drainage. They also give rise to some of the characteristic features of deltas, such as broad marshes and shallow lakes. Upon this peculiar surface, where the rivers at time of high water are higher than the plain, surplus water from rainfall or river overflow cannot joint the main river drainage because it would have to flow uphill to do so. As a consequence the water accumulates in the low flat areas between the distributary channels in the form of swamps or shallow lakes or finds its independent way to the sea through sluggish creeks which wind across the fringe of coastal marshes. It might be expected that these low areas between the levee ridges would gradually fill with sediment as a result of stream overflow through breaks in the levees; this is apparently true of some deltas. It may be, however, that on others the great weight of the load of sediment deposited there results in a slow diastrophic depression of the whole delta surface, and that this keeps the low areas between the distributaries in a continuous state of near submergence, resulting in swamps and lakes. It is estimated that "the daily load of sediment deposited in the lower delta region of the Mississippi River averages about two million tons."[1] However, the land area of the delta is not enlarging at any such rate as this rapid accumulation would imply if, in fact, it is enlarging at all. It may be that areas of local growth, of which there are some, are counterbalanced by wave erosion about nongrowing portions of the delta margin and especially by slow subsidence of the entire delta region as a result of its increasing weight.

Figure 178 shows the distribution of the principal lakes and marshes of the Mississippi Delta with respect to the major and minor drainage channels and their levees. The swamps of the higher delta contain fresh water and are high enough so that many of them are periodically dry. Before the day of the lumberman they were occupied mainly by a natural vegetation of water-tolerant trees, especially the gumwoods

[1] R. J. Russell and H. N. Fisk. Isostatic Effects of Mississippi River Delta Sedimentation. P. 56. A paper presented at the joint meeting of the International Associations of Geodesy, Oceanography, Meteorology and Hydrography, Washington, D.C., 1942.

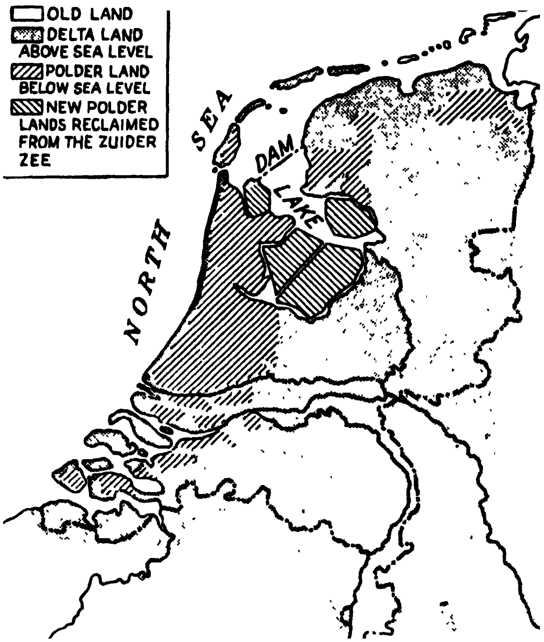


Fig. 183. The extent of reclaimed land in the Netherlands in relation to the area of the Rhine Delta. (*After K. Jansma.*)

and cypress. The swamps of the lower delta and its seaward margin are of two types. Those situated on the low natural levees are wooded, like those of the upstream delta, while those in the still lower interdistributary areas and on the coastal fringe and islands are so little above sea level that they are easily inundated by the sea and have brackish waters. They are never dried out and are covered mainly by vast expanses of tall coarse grasses (Fig. 182).

415. Populous Deltas. Some deltas, both large and small, have very large human populations. The delta surfaces are flat and are composed of new, unleached, and therefore fertile, soils, the silts and clays derived from the great variety of rocks found in the drainage basins of great river systems. Although in their natural state most deltas contain large areas of swampland, their food-producing capacity is large. On the populous deltas the ever-increasing need for land to yield food for so many people has led to most intensive uses of the delta surfaces. The inhabitants of parts of the Ganges Delta, for example, grow a long-stemmed variety of rice whose rapid growth keeps pace with the rising waters of the flood season. The people of some other delta regions have found it necessary to change some of the natural features of the delta or to alter the normal processes of stream overflow and deposit of sediment. Means of better adapting the features of delta surface to human use are found in the stupendous drainage projects of the Rhine Delta and in the irrigation projects of the Nile and other deltas.

416. *The Netherlands coast* includes the merged deltas of the Rhine, Meuse, and Scheldt Rivers. Originally the region had the features common to delta surfaces, and the streams, by flood, built their levees and extended the coastal marshes seaward. Through several centuries a growing need for land has encouraged the inhabitants of this region to reclaim the marsh lands and actually to crowd the sea off the delta margin. Small areas of lower levee and interlevee swampland have been, one after another, made secure from flood by constructing artificial levees, or dikes, entirely around them. Each enclosed area, called a *polder*, is kept sufficiently drained for agriculture by a network of drainage ditches leading to a pump at the lowest corner of the polder. This lifts the water from the polder into a bordering stream or canal which lies between dikes or in channels on top of the dikes. In time new polders were made near the old, and eventually the sea was encroached upon. Now large areas of drained lands lie between 5 and 10 ft., and some are as much as 15 ft., below sea level. The older polders, of which there are hundreds, are irregular in outline and formerly were pumped by picturesque windmills. The newer ones, designed with modern engineering skill, are larger and more regular in shape and are pumped by engines. The newest and greatest project has been designed to cut off and drain the Zuider Zee, a great and shallow coastal embayment, which was much like Lake Pontchartrain near New Orleans (Fig. 183).

417. *The great delta of North China* is comprised largely of loessial silts derived from the highlands of North China and deposited by the Hwang and some other streams. So abundant are the sediments that they have filled a broad

embayment of the Hwang Hai (Yellow Sea) and half surround a large, hilly island which once stood in it. This former island is now the Shantung Peninsula (Fig. 184). The Hwang flows across the northern part of its plain on a levee ridge which in places is as much as 20 ft. high. It is depositing silt so rapidly that frequently the river overflows the artificial levees built to hold it and, like the Mississippi, spreads over the adjacent delta surface. Owing to the silting of its channel the Hwang is of little use for navigation. At times of low water the inhabitants remove large quantities of silt from the stream bed partly to keep the channel open and partly because of the value of the mud as a fertilizer. The rapid aggradation of the delta surface near the stream is attended by the danger of a sudden change in its course during time of flood. Some of the changes are minor, but the stream has several times shifted its course to the opposite side of the Shantung Peninsula. Such a change, on a densely peopled plain, is a major disaster. In 1852 the stream changed from a course on the south side of the plain to near its present course on the north side of the Peninsula and emptied into the sea more than 250 miles distant from its former mouth. In addition to the several major changes, there are unnumbered smaller ones recorded in the 4,000 years of Chinese history. Each has been accompanied by appalling loss of human life.

418. *The Great Delta Plains of Arid Lands.* A few of the great delta plains of the world are in the coasts of deserts. They are built by large streams that are fed by the abundant precipitation of mountain regions and have sufficient volume to flow completely across the desert areas with few tributaries and to discharge their loads of sediment into the bordering seas. Such may be called exotic streams. Outstanding among them are the Nile, the Tigris-Euphrates, the Indus, and the Colorado. The delta of the first named has a density of human population comparable with that of the plain of North China. The people are supported by agriculture which depends almost wholly upon the practice of irrigation, to which the configuration of the delta surface lends itself well. In these arid-land deltas the main problem is not, as in the Netherlands, to lift the water up from the delta surface into the distributary channels but to get it from the channels out upon the delta surface, which is much simpler. In times of high water it may be accomplished by gravity alone. In times of low water lifting may be resorted to, or, by damlike structures, the river level may be raised until only a small lift, if any, is required, to take water out through ditches in the levees, whence it may be distributed by gravity down the gentle back slopes of the levees which are the cultivated farm lands. The deltas and floodplains of these major exotic streams, therefore, constitute one class of desert oasis. They are the largest and most productive oases in the world.

The Nile, after receiving its last important tributary, traverses 1,000 miles of desert, where it loses volume by the removal of water for irrigation, by evaporation, and by seepage. It arrives at the upper delta much decreased in volume. On the delta so much more water is required for irrigation that only a little is dis-

Fig. 184. The great delta of North China, its relation to the Shantung Peninsula, and some of the many channels the river has occupied within historic times. (*After maps by G. B. Cressey and D. W. Mead.*)

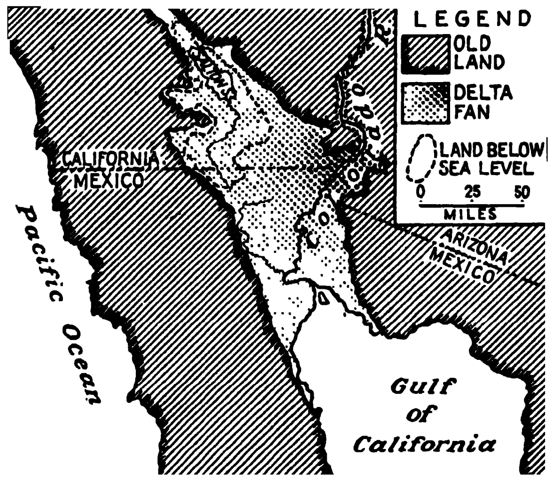


Fig 185. The apex of the delta fan of the Colorado River is at the east side of the long embayment into which it is built. The location and extent of Salton Sink are indicated by the broken line. Salton Sea lies in its lowest portion, its bottom 274 ft. below sea level.

charged through the distributary mouths into the Mediterranean Sea. Several important consequences arise from this fact. (*a*) There are no disastrous floods on the Nile Delta. (*b*) So much sediment is discharged on the delta head and so little about its margins that the surface has a slope of about 60 ft. per 100 miles, three times that of the Mississippi Delta. (*c*) The steeper slope and smaller water supply make drainage easier. Nearly the whole surface is cultivated, and lakes and swamps are found only about the delta margins.

The delta of the Colorado River has been built into and across the northern portion of the long tectonic depression occupied by the Gulf of California. It was built in from the east, and after extending across to the western wall of the depression it blocked off about 150 miles of the former upper end of the Gulf. Evaporation of the water there has left the plain called the Salton Basin, a part of whose floor lies nearly 275 ft. below sea level. Water from the Colorado River is distributed by ditches over the surface of the delta for the irrigation of crops. Although the river now discharges southward into the Gulf of California it has several times shifted to a northward distributary and emptied into the low basin called Salton Sink (Fig. 185). The whole delta area is known as the Imperial Valley.

Floodplains

419. Floodplain and Delta. Floodplains are the alluvial deposits spread by aggrading streams upon the floors of their valleys during the process of valley widening and stream overflow (373). The floodplain begins to form in the lower course of the stream where it first reaches grade. This is the same point at which the delta begins to form. As the delta grows seaward the decreased stream gradient (413) causes frequent stream overflow, during which sediment is deposited not only at the delta head but also in the lower stream valley and thence progressively upstream (Fig. 186). Thus the two are blended, and it is difficult to say just where delta ends and floodplain begins. However, some streams that have no deltas have well-developed floodplains.

420. The Width of Floodplains. Floodplains are confined within the bluffs cut by the lateral erosion of a meandering stream (370). The valley walls may not be high, and usually they are much gullied, but they mark an abrupt change from a stream-dissected upland on the one hand to a flat plain of recent alluvium on the other (Fig. 187). The width of a floodplain, *i.e.*, the distance from one valley wall to the other, depends much upon the size of the stream that builds it and upon its stage of advancement

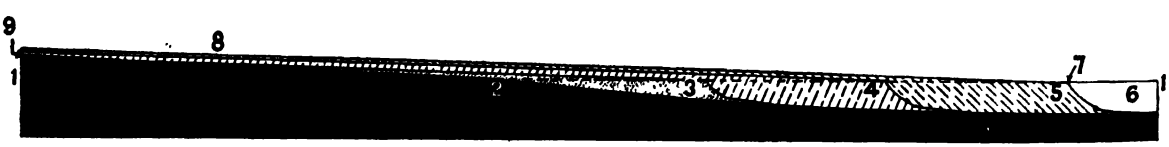


Fig. 186. A longitudinal profile of a delta to illustrate the merging of floodplain and delta surfaces. (1) Sea level; (2) original shoreline; (3) small delta; (4) delta elongated and stream grade raised; (5) present delta front; (6) sea; (7) present shoreline; (8) present stream grade in which delta and floodplain merge; (9) original stream grade.

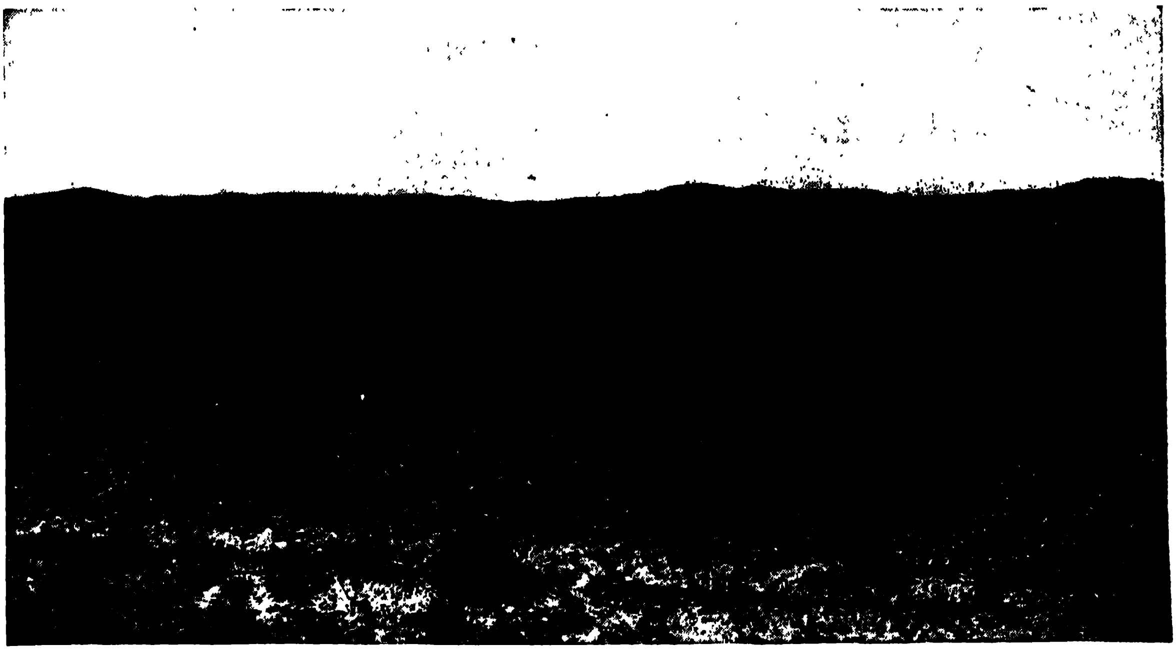


Fig. 187. The flat surface of the Platte River floodplain in western Nebraska contrasted with its abrupt and dissected bluffs. Compare with Figs. 150*E* and 162.

in the cycle of river development. In the valleys of small but aggrading creeks it may be only a few yards. In the valleys of large streams the plains may be of any width up to several miles. Usually they narrow in the upstream direction toward the headwaters, where the tributary streams may be so young as to have no floodplains at all. The Mississippi floodplain, where the stream flows between Iowa and Wisconsin, is 1 to 3 miles wide; in the latitude of southern Illinois it is about 6 miles; but below Cairo it broadens rapidly and, including the plains of minor streams that join it, ranges between 25 and 75 miles in width. It is reported that the floodplain of the lower Amazon, the greatest of all rivers, generally is less than 30 miles wide.[1]

421. The Floodplain Surface. The surface features and the conditions of drainage that characterize the typical floodplain are similar to those of the upstream part of a delta. It is comprised principally of a monotonously flat surface upon which areas of levee land alternate with areas of swamp. On small floodplains the levees that border the stream often are so small as to be hardly noticeable. However, bordering meander bends, they are likely to be enough higher than the remainder of the floodplain so that they interfere with the drainage of water from the bluffs toward the stream. For that reason swamps or marshy spots are likely to be found toward the margins of the plain between the stream and the valley walls (Fig. 188).

The distribution of levee and swamplands on broader floodplains usually is not so simple as that indicated above. The valley floor is a place of rapid change. It is widened and shaped by erosion and deposition which go on at the same time. It is the work of a meandering stream which touches first one valley wall and then the other. A meander curve becomes elongated by deepening of its channel and slumping on the outside of its bend and by deposition of the inside (Fig. 153). By this process also the meanders themselves tend to migrate slowly in the downstream direction, changing both their shapes and their positions. In times of high water their changes are rapid. Increased volume gives temporarily increased transporting power, and overflow causes the deposition of much sediment upon the immedi-

[1] C. F. Marbut and C. B. Manifold. The Topography of the Amazon Valley. *Geog. Rev.*, Vol. 15, p. 617, 1925.

Fig. 188. The floodplain and levees of a small stream among the hills of Japan. The stream may be located by noting the footbridges that cross it. The path follows one levee, and rice fields lie on the lower levee and floodplain surfaces.

ate stream banks, raising the levees. The general effect of these activities is that alluvium is picked up in one locality and put down in another, distributed and redistributed over the valley floor, and that levees are broadened by overflow here and narrowed or lowered by erosion there. Eventually meanders that have grown overlong are cut off and abandoned by the stream when it shortens its course by cutting through a narrowed neck of alluvium (Fig. 150*E*). The ends of the abandoned meander channel presently are filled with silt, and the unfilled portion exists as a horseshoe-shaped pond, or *oxbow lake*, bordered by its levees. Lakes of this kind no sooner are formed than they begin to be filled and obliterated (*a*) by sediment deposited during general river floods, (*b*) by rain-washed sediment from the adjacent surface, and (*c*) by the growth and decay of aquatic vegetation. The surfaces of broad floodplains are likely, therefore, to contain many oxbow lakes in all stages of destruction. Some, which are of recent formation, appear as curving open lakes; some contain but the dwindled remnants of abandoned channels; others remain as boggy, sedge-filled marshes; while still others may be described only as *meander scars*. The latter are marked by bits of woodland swamp or low ground, the horseshoe-shaped outlines of which hardly would be noticed save from an airplane (Fig. 189). Associated with each of these abandoned channels are sections of abandoned levees, also in various stages of destruction (Fig. 190).

Another element in the pattern of the broad floodplain is furnished by small tributary streams. Small streams entering the plain from the bordering uplands are sometimes prevented from joining the main stream at once because of the upward slope of its natural levees. Instead they turn down valley and, after paralleling the main stream some distance, find a place of entrance (Fig. 191). To the features of the floodplain, therefore, are added the meanders, oxbow lakes, levees, and swamps created by tributary streams. In consequence, the broad floodplain is likely to have a complicated pattern which may consist of meandering stream channels, large and small, of new levee lands, old subdued levees, oxbow

Fig. 189. An air view of the small floodplain of the La Crosse River, Wisconsin, showing numerous scars of abandoned meanders, many of them now cultivated. (*Official photograph, U.S. Army Air Corps.*)

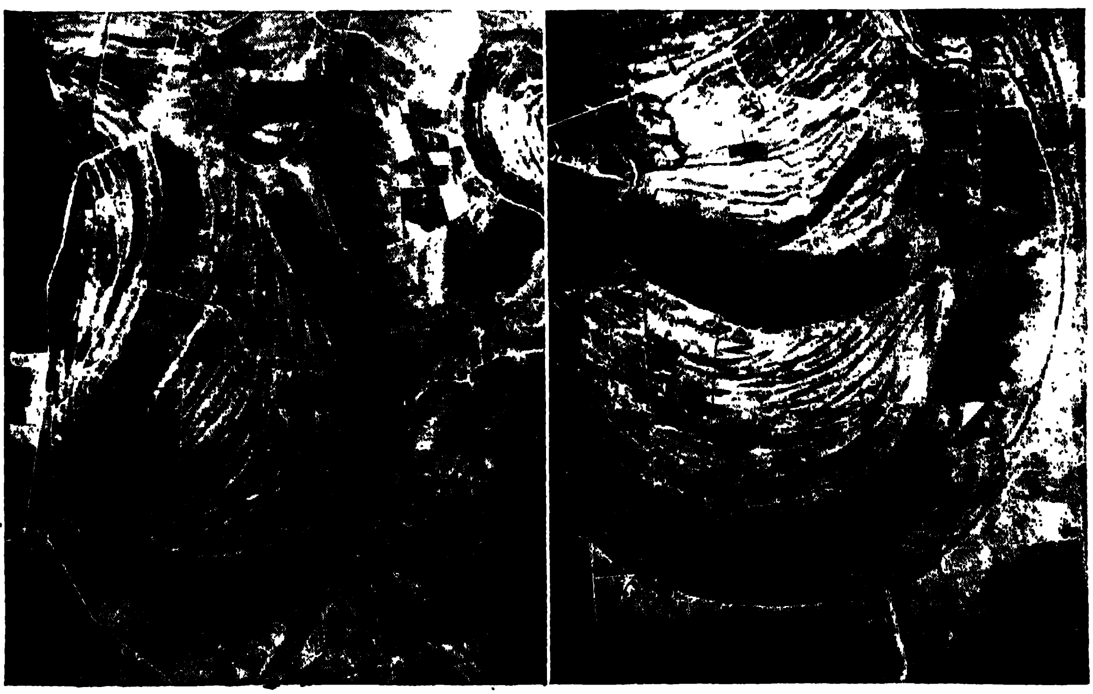


Fig. 190. An oxbow swamp and other great meander scars on the lower Mississippi floodplain, viewed from the air. The color intensities in the photographs indicate differences in the vegetation, either natural or cultivated, which in turn indicate differences in soil or drainage. (*Official photographs, U.S. Army Air Corps. Courtesy of U.S. Geological Survey.*)

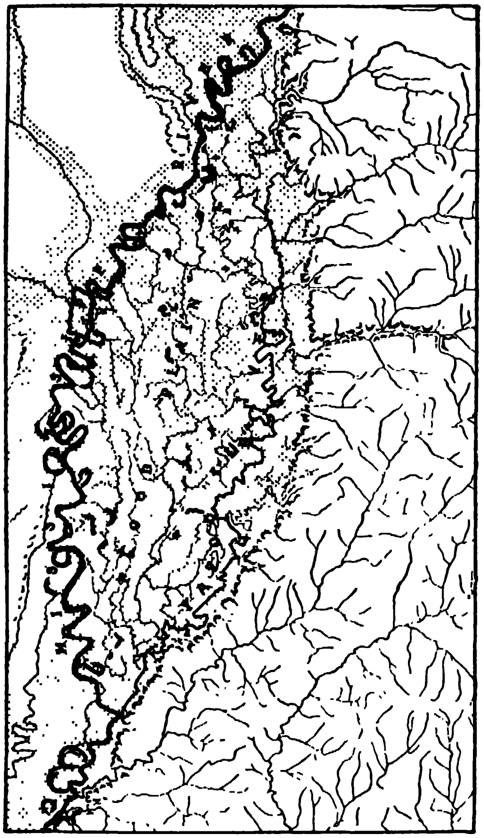


Fig. 191. After the upper headwaters of the Yazoo River enter the broad floodplain of the Mississippi, it follows an older stream course for 175 miles along the bluffs before it joins the larger stream.

lakes and their swampy remnants, together with broad floodplain marshes. The silts and clays deposited on broad floodplains make productive soils, and generally they are used for agriculture. The levee lands are naturally the best drained and are the first to be used. On the Mississippi floodplain large areas of swampland remain unreclaimed. On some Old World floodplains, however, such as those of the Nile and Yangtze, where land is scarce and life and labor cheap, even the swamps are drained and cultivated.

422. Alluvial Terrace Lands. Many floodplains are fringed at intervals with smaller alluvial plains which stand at elevations somewhat above that of the present plain. These are called *alluvial terraces*, or benches. Although they lie above the floodplain, they are unlike the valley walls which flank them in that they are stream deposits. Usually they are bordered by abrupt descents of a few feet to the level of the newer plain. They are the remnants of older and higher floodplains into which the stream has subsequently eroded a new plain, owing to some cause that has decreased its load of sediment or has increased its carrying capacity. Some valleys exhibit a series of alluvial terraces at different levels which mark stages in the erosion of the old valley filling (Fig. 192). Although alluvial terraces seldom are high or continuous, they frequently contain many acres and sometimes many square miles of land. Because alluvial terrace land is sufficiently above present river level to be free from floods, it generally is well drained and admirably adapted to cultivation. However, because the terrace is above the present flood level its soils are no longer enriched by additions of alluvial mud and, being older, they are, in regions of abundant rainfall, likely to be somewhat leached. Sites of this kind are suitable also for river towns. The inhabitants of floodplains commonly distinguish between the present floodplain and successive terrace levels by speaking of them as "first bottoms," "second bottoms," etc.

423. Floodplains and River Floods. The flatness of floodplains, the nature and direction of their levee slopes, and indeed the very manner of their formation indicate that they are

Fig. 192. A diagram to illustrate the development of alluvial terraces by the partial re-erosion of an older and more abundant deposition of alluvium. Natural levees border the present stream course.

plain. The slopes of the fan are, moreover, not merely in one direction from the mountain base but extended radially from the fan head, giving the fan a slightly convex cross profile. This is a matter of great convenience in use of irrigation water. Because of the radial slope of the fan, irrigation water applied at its upper end may be distributed by gravity to all parts of the fan surface.

425. Piedmont Alluvial Plains. The bases of mountain slopes in dry and subhumid climates commonly are fringed by alluvial plains comprised of coalesced fans, some of which are large and some small, their size depending upon the volumes and deposits of the several streams draining the mountain front. The heads of the several fans may be distinguished at the mouths of the valleys (Fig. 193). They are composed largely of gravel and sand, and their surfaces often are strewn with boulders distributed by flood waters following torrential rains in the mountains. The porosity of these coarse soils, their inability to retain irrigation water, and their bouldery surfaces cause the higher parts of the fans to be somewhat avoided for intensive agricultural use, although they may furnish gravel and sand for constructional purposes (Fig. 194). At no great distance from the mountain front the slopes of the bordering fans flatten out, their soils become finer, their margins spread, and they merge into a continuous alluvial plain (Fig. 195). Such a plain may appear practically level, yet it is not so in fact. Not only does it slope away from the mountain base, but each of its component fans has its faintly convex surface, and where they are blended together the resulting plain has a scalloped margin. Between the individual fans are broad shallow depressions.

Many piedmont alluvial plains are covered only with desert shrubs or sparse grasses, but the fine dry-land soils are high in mineral plant foods, and such as have available supplies of irrigation water are capable of great productivity. Although their surfaces are dry, natural conditions provide many alluvial fans with

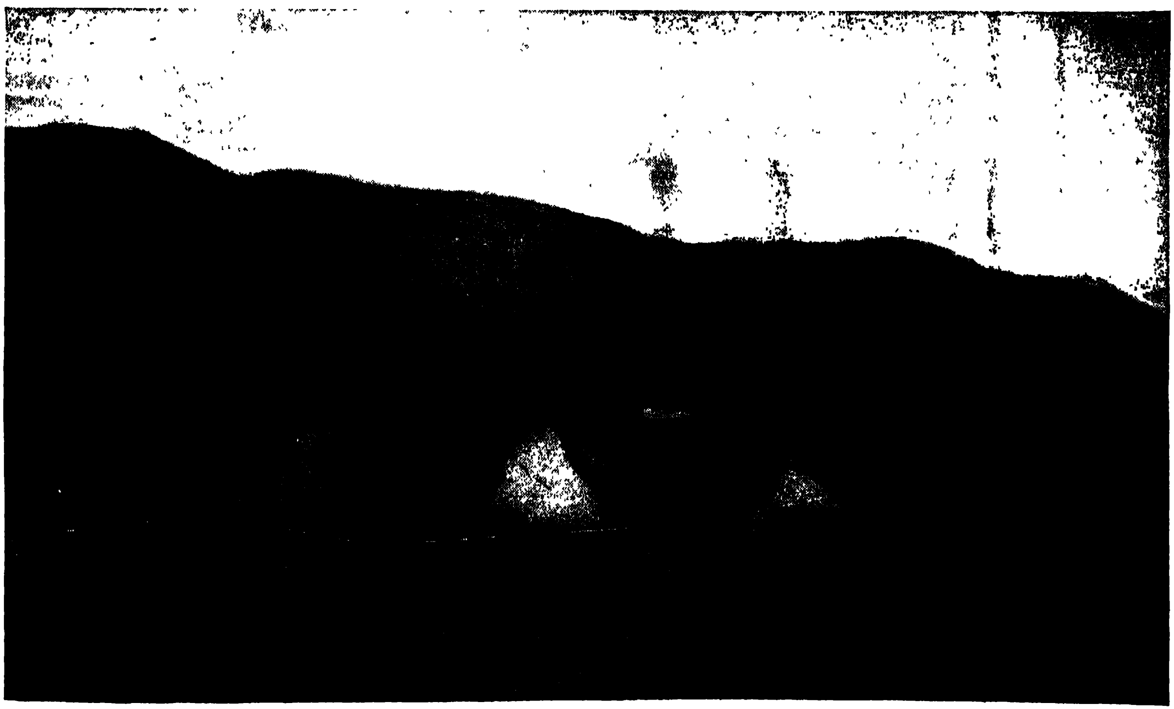


Fig. 194. The coarse deposits of the upper part of a large fan in California provide a supply of commercial gravel. The nearly level surface of the fan, where the machinery stands, is in striking contrast with the slopes of the mountains behind it.

Fig. 195. A profile view of a series of alluvial fans merged into a small piedmont alluvial plain which borders low mountains in the San Fernando Valley, California. The steeper upper slope of one fan (seen at the left center), where it heads between the mountain spurs, may be contrasted with the more gentle lower slope toward the right.

supplies of water for irrigation. (*a*) The water of the mountain stream that builds a fan may be impounded in its mountain valley whence it may be led out upon the fan surface. (*b*) The natural stream flow disappears, except in time of flood, into the coarse debris of the fan head. However, it collects underground in the great storage reservoir of the porous fan material and slowly seeps outward toward the fan margin. This water commonly is recovered for use in irrigation, in some regions through wells, and in others, as in parts of Asia, through tunnels driven underneath the fan surface. In the Hami oasis in Chinese Turkistan, for example, much of the irrigated land is supplied with water from springs that issue from the mountain bases, some is supplied from mountain streams, and a considerable part is derived from subterranean sources. Lacking the modern pumping machinery used to lift these waters from underneath the fans, as is done in the western world, the farmers of this ancient civilization have devised another method. A series of wells is dug, extending in a line down the profile of a fan, and the bottoms of these are connected by short tunnels. Thus is formed an underground canal called a *kariz*. It has a grade less than that of the sloping fan surface and comes to the surface on the outer part of the fan. From a series of kariz, waters are obtained to irrigate a part of the piedmont plain.[1] Similar underground canals, called by other names, are widely used in irrigating piedmont alluvial plains which border dry basins in many parts of interior Asia.

Just as the floodplains *above* some irrigated deltas are irrigated, as in the case of the Nile, so are some of the floodplains *below* or beyond the lower margins of alluvial fans. Provided the supply of water is sufficient, it is sometimes led by canals out beyond the irrigated areas of the fans and applied to the alluvial valley bottoms as far as the supply permits. The slopes of fans and piedmont alluvial plains may be recognized, therefore, as a second class of oasis only a little less extensive than that associated with the deltas and floodplains of exotic streams (418).

[1] Tsu-yu Chow. Unpublished paper.

426. Alluvial Basin Plains. Some structural basins or valleys are nearly encircled by fans which extend inward from the flanking highlands and create alluvial plains which slope gently upward from low central portions toward their highland margins. Beneath some such plains the accumulated fan deposits are deep, and the basins are said to be alluvium filled. The mountain drainage which seeps through the porous upper parts of the fans in a filled basin sometimes reappears as ground water about the lower edges of the concentric fans. For that reason alluvium-filled basins, even under arid climate, commonly have at their centers areas of marsh, shallow lakes, or alkali flats (454).

427. Noted Piedmont Alluvial Plains. Because piedmont alluvial plains have deep fertile soils and are admirable sites for the practice of irrigation, some of them, which have abundant and dependable water supplies, are noted for their agricultural wealth. Among them are the Sacramento and San Joaquin Valleys of California, the Los Angeles-San Bernardino lowland of Southern California, the Vale of Chile, the Samarkand district of Russian Turkistan, the Tarim Basin, and many others. Conditions in the San Joaquin Valley illustrate the landforms developed by valley filling.

The San Joaquin Valley portion of the Great Valley of California is a structural trough between the Sierra Nevada Range and the Coast Ranges. From the latter more than 50 small wet-weather streams flow eastward into the basin, bringing alluvium which is spread in a seemingly flat and quite featureless plain along the western margin of the valley. Drainage from the abundant snows and rains on the windward, west-facing slopes of the higher Sierra Nevada Range is carried down to the eastern margin of the valley by eight large streams and more than a dozen smaller ones. These have contributed alluvium to the general filling of the valley and have, in addition, built large alluvial fans. The largest of the fans is that of Kings River. It spreads outward into the valley 50 miles from the mountain base, crosses the axis of the structural trough, and blocks the drainage of its dry southern end (Fig. 196). Thus Tulare and Buena Vista Lakes are created, and areas about the margins of the fans are made marshy. Large supplies of irrigation water from the snowy Sierras supplied to the gently sloping and highly tillable piedmont plain have turned each great fan into an oasis upon which there is an intensive agriculture devoted principally to fruits. This contrasts sharply with the extensive livestock-ranch type of agriculture that prevails on the western margin of the plain which lies in the rain shadow of the Coast Ranges and has only limited supplies of irrigation water.

428. Delta Fans. Some streams that have fairly steep gradients and are abundantly supplied with sediment enter the sea and build deltas. As these grow, their flat surfaces serve further to check stream velocity, fans form upon the delta tops, and the two grow in association. Such features may be called delta fans, and some of them are of great size. The delta of the Colorado River is, in fact, a large delta fan. Small delta fans occupy fringing embayments of many mountainous coasts, as, for example, in Japan, where various of the small marginal

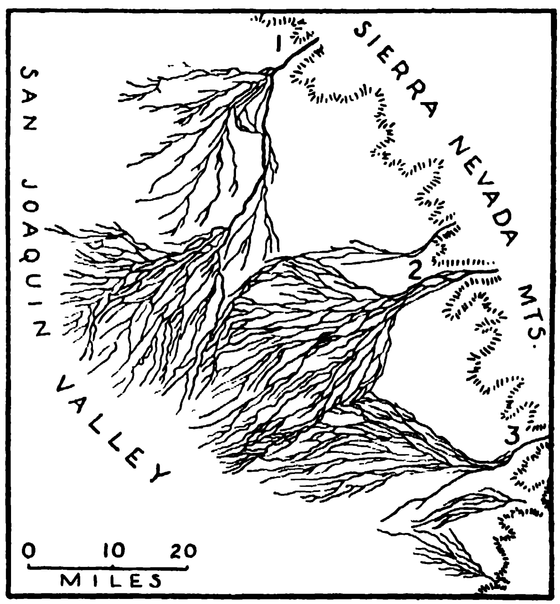


Fig. 196. A map showing the intricately branching patterns of the temporary distributary channels on the alluvial fans of the (1) Kings, (2) Kaweah, and (3) Tule rivers, California.

plains are delta fans. Some of them are bounded on the landward side by the abrupt escarpments of recent faults. These steep slopes, composed in part of volcanic ash, older alluvium, and other easily eroded materials, furnish so large a supply of sediment that the streams, even in that rainy climate, cannot transport it fast enough to prevent the accumulation of fans. In a land so generally mountainous as Japan, these fragmentary but fertile plains are densely peopled and intensively used. Of similar construction are the productive lowlands of Valencia, Spain, and the Canterbury Plain, a gently sloping plain 40 miles wide and 175 miles long on the east coast of South Island, New Zealand. Each of them, however, is made up of the combined delta fans of several streams which drain the bordering mountains, and they might properly be called "piedmont alluvial delta-fan plains," if one wished to employ a term so awkward.

Plains of Older Alluvium

429. The Nature of Older Alluvium. Certain of the world's considerable plains are described as plains of older alluvium. The material composing them differs from that of recent alluvial plains in being much older. In humid climates it is generally much leached and less fertile. In some regions it has been changed into weakly cemented rock. These plains have been so long deposited that their surfaces have lost most of the distributary channels, levees, and other forms characteristic of recent alluvial plains and now have features that are more the result of erosion than of deposition. In consequence of these changes they generally are well drained. The internal structure of such plains betrays their origin, however, for they are unlike the well-stratified marine sediments of coastal plains in that they are made up of the irregularly bedded deposits of ancient streams.

The largest plains of this type are distributed beyond the margins of great mountain systems and were no doubt, at the time of their formation, vast piedmont alluvial plains. Subsequent diastrophic or other changes of condition have caused the present streams that cross them to cut new valleys into the surfaces of the plains and to build floodplains of new alluvium across them at somewhat lower levels. Above these new floodplains, areas of the older alluvium stand as separate and sometimes isolated plains. Many of them are bluff-bordered, tabular in form, and have surfaces that are gently undulating or even so flat that they are poorly drained. Some have also in their surface layers a considerable admixture of volcanic ash and loess, the accumulation of a long period of time.

430. Important Plains of Older Alluvium. There are many small plains of older alluvium. In Japan old delta fans, uplifted relative to sea level since their formation, are now dissected by streams and stand as islands of older alluvium in the newer plains or as terraces between the newer plains and the mountain slopes. Because of their greater age and exposure to leaching, under heavy rainfall, the small plains of older alluvium have red soils of greater maturity and lower fertility than those of the plains of new alluvium. Moreover, because of their porous ashy soils and their elevated position, they have excessive drainage, and it is difficult to get irrigation water to them for the cultivation of rice. Consequently the manner of their agricultural utilization is entirely different from that of the newer floodplains and delta fans.

Some plains of older alluvium are of vastly greater size than those of the type illustrated in Japan. In northern India the broad structural depression of the middle and upper Ganges and Indus valleys is filled to great depth with older alluvium. Into its surface the present streams that drain the Himalaya mountain front have cut new valleys as a result of an increase of elevation with respect to sea level. There they have constructed floodplains of new alluvium. The interstream areas, there called *doabs*, are tabular or mesalike remnants of an ancient alluvial plain. Some of these are of large area, but generally they are less productive agriculturally than the present floodplains. A similar situation is found south of the Alps. Deep accumulations of older alluvium are there spread out upon the northern flank of the Po

CHAPTER 16: *Glaciated Plains*

431. Classes of Glaciated Plains. In northern North America and northwestern Europe are extensive glaciated plains (376). Their original surfaces were developed by stream erosion on both complex crystalline rocks and those of simple sedimentary structure. Although the larger relief features of these plains were produced by tectonic forces or by stream erosion, most of the details of landform that characterize their present appearance are the result of glacial action. Therefore, while these great plains already were plains before the time of glaciation, their surfaces were extensively remodeled by the work of ice.

All phases of glacial activity were involved, and their imprints are left upon the plains. In many localities there may be found in close association, and in great variety of detail, the forms produced by glacial erosion, glacial deposition, and deposition by the waters that flowed from the melting ice. It is recognized, however, that within the regions of continental glaciation some areas have predominantly the kinds of surface features that result from glacial erosion while in others the features are mainly those that result from glacial or glaciofluviatile deposition. Plains thus distinguished may be called *ice-scoured plains* and *drift plains*, respectively. It may be observed in this connection that plains of the ice-scoured type are most prevalent in regions of crystalline rocks and that they are on the inner rather than on the marginal portions of the glaciated areas (Figs. 155 and 219). There the thin regolith and the general resistance of the rocks provided relatively small amounts of local glacial drift. That which was formed was comprised in large part of rocks resistant to glacial crushing, and these remain as coarse boulders intermingled with some quantities of finer material. The plains of deep glacial drift are found more commonly in association with regions of sedimentary rocks, which generally were more deeply eroded and more easily crushed than those of the crystalline areas. It may be noted also that, in both North America and Europe, the direction of ice motion was generally away from the regions of crystalline rock toward those of sedimentary formation and that, therefore, some of the products of ice erosion in the crystalline areas were deposited elsewhere. That is the reason for the numerous *erratic boulders* of igneous or metamorphic rock found in drift plains which are underlain by sedimentary rock only (378).

The features of the two classes of Glaciated Plains may be discussed separately.

The Features of Ice-scoured Plains

432. The Ice-scoured Surface. The major stream-eroded hills and valleys that previously existed on the plains over which the great continental ice sheets crept probably were not completely erased by glacial scour in most instances. Almost universally, however, they were reshaped by an ice sheet thick enough to bury them deeply beneath its overpowering weight. A first ice invasion of a region doubtless was sufficient to remove the mantle of soil and weathered rock which had accumulated there under previous conditions. Angular profiles, where such had been developed by the usual processes of weathering and stream erosion in rocks of unequal hardness, were then subdued by glacial erosion.

The surface configuration of the hard rock

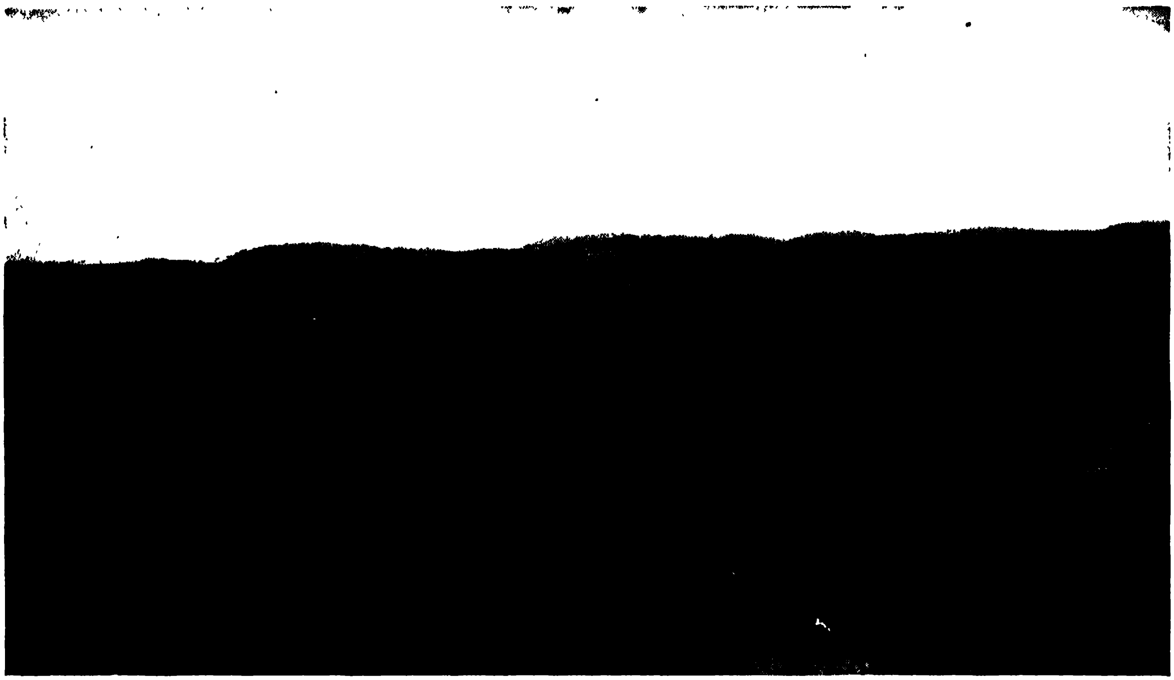


Fig. 198. The rounded uplands and rock basins of an ice-scoured surface in northern Canada, where vegetation is scant. Note the different elevations of the lakes. (*Royal Canadian Air Force photograph.*)

plains where ice scour was predominant is characterized by rounded rock hills and broad open valleys and basins with comparatively low local relief. This resulted from the quarrying out of areas of much-jointed rocks, leaving an uneven surface of knobs and hollows on the massive rocks beneath. Upon this the ice continued to flow, smoothing and rounding but unable to effect further great change. Over the present valley floors a thin veneer of glacial debris may serve inadequately as the parent material of a soil. Strewn with subangular boulders (377) torn from the adjacent slopes by the ice, the drift of ice-scoured plains commonly is neither deep enough nor continuous enough to be tillable except in patches or localities. It may, however, serve as anchorage for stands of forest, especially the shallow-rooted conifers. Through the veneer of drift, which sometimes barely covers the lowlands of the ice-scoured rock surface, project the smoothed and rounded tops of rock hills still less completely covered (Fig. 198). Many of these rock hills are entirely without soil covering, except the small quantities of earth lodged in joint cracks and other pockets. Such surfaces, scoured and polished by ice erosion, often bear the grooves and striations scratched upon them by ice-pushed boulders. In some localities groups of ice-scoured hillocks protrude above the drift-covered slopes. They have been called *roches moutonnées*. Some larger hills of the same origin have striking inequalities of slope (Fig. 199). A long and gradual incline marks the side up which the ice pushed its slow and grinding way, and the lee slope is left shorter and steeper as a result of the quarrying or plucking action of the ice as it pulled away jointed blocks of rock in its forward motion.

433. Drainage Forms in Ice-scoured Plains. The changes in relief produced by ice scour are not of a large order of magnitude as compared with some produced by other agents, but they are sufficient to disarrange completely the preexisting drainage. It may be supposed that, during the long period of preglacial erosion, streams had become somewhat adjusted to the kinds and structures of the rocks of the plains and that they had developed definite patterns as the result of that adjustment. The present

areas of most recent glaciation, has various classes of features arranged in diverse but recognizable patterns. The most extensive and fundamental element in this complex is the till sheet or ground moraine, an undulating surface which covers most of the area once occupied by the glacier. About the margins of the till sheet, and also upon its surface, may be found varying amounts of the other classes of deposits. Ridgelike marginal moraines (end or recessional) often are arranged in broad festoons, one behind another (Figs. 203 and 211). Bordering them, either beyond the till sheet or upon its surface, are areas of stream-sorted and deposited sand and gravels or beds of fine sand and clay which accumulated in transient stream channels or temporary lakes.

Each major class of drift is characterized by distinctive features of surface configuration and differences in composition which have both advantages and disadvantages for human occupance and use. They may now be presented for more detailed consideration under the following headings: (*a*) *till plains,* (*b*) *marginal moraines,* (*c*) *glaciofluvial plains,* and (*d*) *glaciolacustrine plains.*

437. The Till Plain (378) is a mantle of unstratified drift. It was deposited mainly beneath the glacier but also in part from the earthy materials held on the ice surface and let down upon that beneath when the ice finally wasted away. It is a widely distributed surface deposit and is the foundation upon which other forms of drift rest in many localities. In it are rock materials of all degrees of size from large boulders, such as can be carried only by glaciers, down to the finest of clay or rock flour (Fig. 204). These ingredients are mingled and show little or no separation into strata of different size or weight classes such as are deposited by running water. The till generally is comprised of materials which largely are of local origin. In regions of sandstone bedrock it has commonly a large component of sand, and in shale and limestone regions a large component of clay. Usually, however, there are foreign

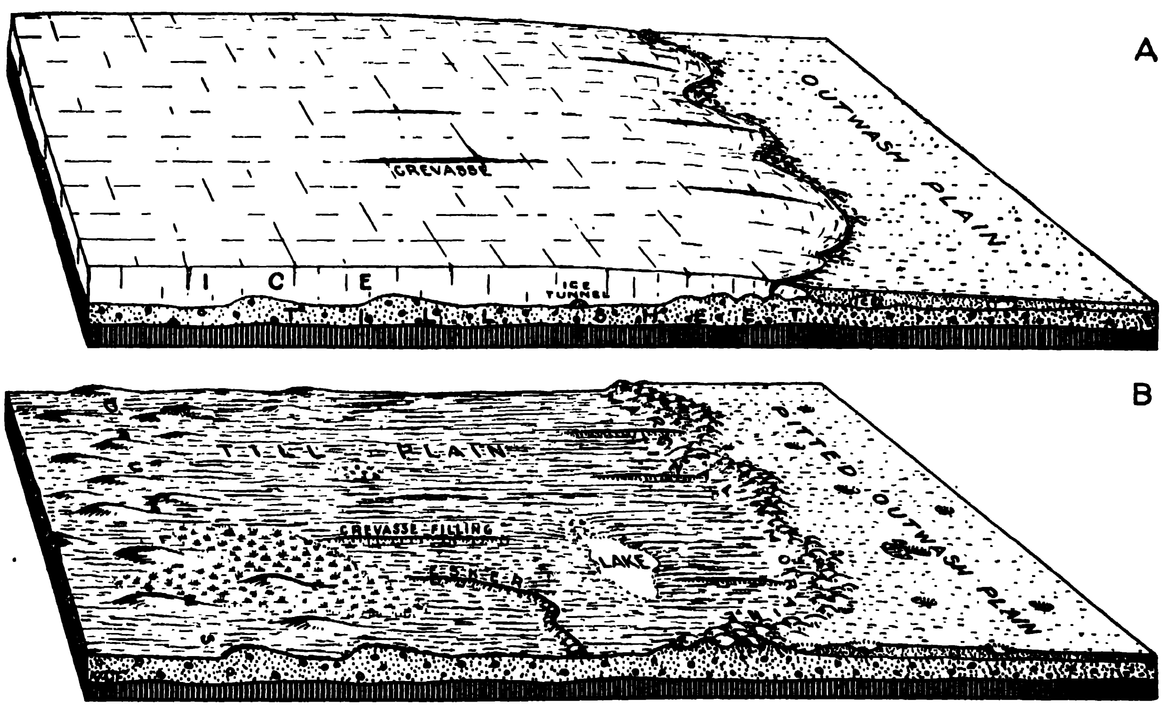


Fig. 203. A diagram to illustrate the relationships of several classes of glacial and glaciofluvial deposits to the parts of the glacier by which they were formed. *A*, a plain partly covered by the margin of a stagnant glacier; *B*, the same plain after the disappearance of the ice by melting and evaporation.

Fig. 204. An exposure of glacial till showing the unassorted clay, pebbles, and boulders of which it is composed. Note the subangular shape of the large boulder at the left. (*Wisconsin Geological Survey photograph.*)

materials present also. Some are fine materials such as sand, clay, and pulverized limestone brought from regions of different kinds of rock. Others, called *erratics*, are pebbles and boulders of harder sedimentary rocks or of igneous or metamorphic rocks which have been transported scores or even hundreds of miles from their nearest known sources. Such rocks often are conspicuous because of their large size or their hard and unweathered condition. Many of them are subangular in shape and show scratches and other evidence of having been reduced in size

Fig. 205. A subangular boulder showing glacial striae. (*U.S. Geological Survey photograph.*)

by scraping and grinding against other boulders and the bedrock during their travels (Fig. 205). In regions of resistant bedrock especially, boulders of local origin may be so numerous in the till as seriously to interfere with the cultivation of the soil. Such is the case, for example, in New England, where the till sheet is thin and the surface features are about as much the result of ice scour as of the deposition of drift. Unlike the normal weathered regolith (Fig. 133), which grades downward into the underlying bedrock from which it is derived, the till sheet, whatever its composition, ends abruptly and rests upon the hard and little weathered surface of the ice-scoured bedrock beneath.

438. The Surface Features of the Young Till Plain. The relief features of the till surface generally are of a minor order of size. The principal and widespread characteristic is a gently undulating surface which includes broad low hills, or swells, and wide shallow depressions, or swales, the latter often without outlets (Fig. 206). These result from the unequal deposition of the ground moraine. The various elevations and depressions are arranged according to no

Fig. 209. The relief pattern of part of a large drumlin region in central New York.

ridge of the preglacial rock surface and has developed falls or rapids of greater permanence having economic value as water-power sites.

The numerous lakes and far more numerous swamps of the till plain lie mainly in depressions due in part to ice scour and in part to the unequaled deposition of the drift. The depressions, or basins, thus formed are of two somewhat different kinds. (*a*) Some are due to the erosional reshaping, unequal filling, and morainic blocking of preglacial river valleys. Some of the lakes formed in such basins are large and deep. Some of the Great Lakes of North America lie in basins that are mainly glacial modifications of preglacial river valleys. Ice scour enlarged these valleys, and morainic dams blocked them, although a gentle crustal warping has also been involved in their formation. Owing to successive drift dams across a single preglacial valley, lakes may occur in succession forming a chain, as does the series of four near Madison, Wis. (*b*) Other basins may be the impressions of large ice blocks which became detached from the margin of a stagnant glacier as a result of melting along crevasses. Basins of these origins may be many square miles in area, or they may be mere ponds, but whether large or small, they are likely to be shallow. Lakes in the smaller morainic basins are maintained by direct rainfall, by springs about their borders, or by inflowing brooks from limited drainage areas.

The relative permanency of the numerous small lakes of the till plain is not great. Inflowing drainage is abundantly supplied with silt and tends to fill a basin quickly. Outflowing drainage is able quickly to cut a notch in the soft morainic rim, lowering the outlet and with it the lake level. Such as are maintained by rain and springs and drain wholly by seepage through the drift depend for their existence upon the position of the ground-water table. In the till plains of America, even before the agricultural occupance of the land during the past century, thousands of lake-filled basins left at the retreat of the last glacier had been filled or drained by natural processes, including the growth of vegetation,

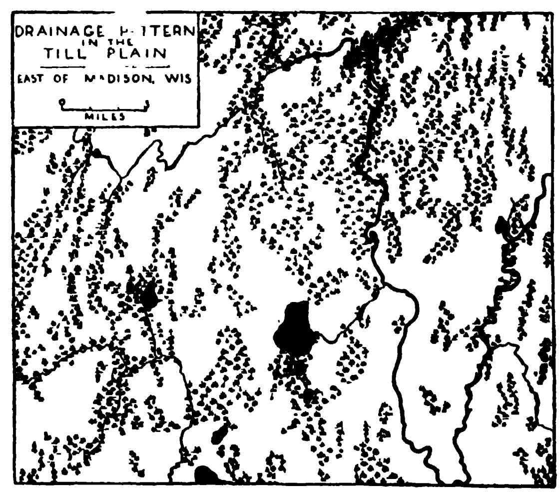


Fig. 210. The drainage pattern associated with drumlins in a portion of a Wisconsin till plain.

and converted into marshes. Generally the basins are partly filled with peat, the acid half-decayed remains of rank vegetative growths. Some are now covered with grasses and appear as marsh meadows. During the last century other thousands of small lakes and ponds in America have dwindled in size or have become marshes, owing to the increased rate of fill resulting from clearing and plowing on adjacent hillsides or to the lowering of the ground-water table which follows general deforestation. Also, thousands of acres of small marshlands have been artificially drained and their surfaces put to agricultural or pastoral uses.

440. Marginal Moraines and Their Arrangement. A period of balance between the rate of glacial advance and the rate of melting permitted the position of the ice *margin* to remain stationary or to change but slightly. During such a time the moving ice continued to drag forward in its bottom, or to carry forward in its mass or on its surface, quantities of drift all of which were deposited at favorable places about its relatively stationary margin as a *marginal moraine* (379, Fig. 203). Thus were created discontinuous ridges or belts of drift of greater thickness than the till sheet and with notably different detail of form and pattern of arrangement.

Periods of temporary marginal halt occurred (*a*) at the place of its greatest advance, during the time of hesitation between general advance and excessive wastage; and (*b*) at intervals of temporary readvance, during the long time required for the slow and complete wastage or melting back of the glacier. Moraines put down about the margin of the ice at its most advanced position are called *end moraines*. *Recessional moraines* were built upon the top of the till plain at places of hesitation or temporary readvance during glacial wastage. It appears to have been a general condition of glacial disappearance that atmospheric temperature, the supply of snow, or other elements of environment caused the rate of waste to be most irregular. Advances, or slight readvances, during which marginal moraines great or small were formed, alternated with periods of waste so rapid that only small amounts of marginal deposit were put down upon the surface of the till. This is indicated by successive morainal ridges separated by areas of till plain.

The patterns of arrangement of marginal moraines greatly affect the appearance and use of regions in which they occur, and also they may be used to indicate the extent of the area covered during the period of greatest glacial advance or at any stage during its retreat. It is certain that all parts of a long ice front of 1,000 to 2,000 miles neither advanced nor wasted away as a unit but did so unequally as a series of lobes or tongues separated by embayments. Evidence of that is found in the pattern of arrangement of the principal end moraines and other marginal moraines left by the last continental glacier of North America. They form a series of intersecting arcs or of interlacing and irregular scallops (Fig. 211).

441. The Size and Composition of Marginal Moraines. Marginal morainal ridges vary greatly as to size, form, and continuity. Some are so meager as to be hardly noticeable; others are single narrow ridges a few yards in width and only a few feet high. However, some are comprised of belts rather than ridges of drift and have rough or strongly undulating surfaces which are pitted with steep-sided depressions. These belts commonly are 1 to 5 miles in width, many miles long, and contain hills which reach elevations 100 to 200 ft. higher than that of the bordering till plain. Such moraines clearly were not deposited by the ice while its margin remained unmoving. They are compound ridges resulting from deposition during a period of many minor changes of position.

The drift that makes up marginal moraines includes both unstratified and stratified forms. Much of the material, having been pushed forward into its present position by an advancing ice edge, is boulder clay, like that of the till plain. Other parts, and especially the surface materials, were deposited with the partial aid of waters flowing from the melting ice and issuing from channels on the ice or under it. The effect of stream sorting on the drift was to remove the clay and other finer materials and transport them out beyond the marginal moraine. That

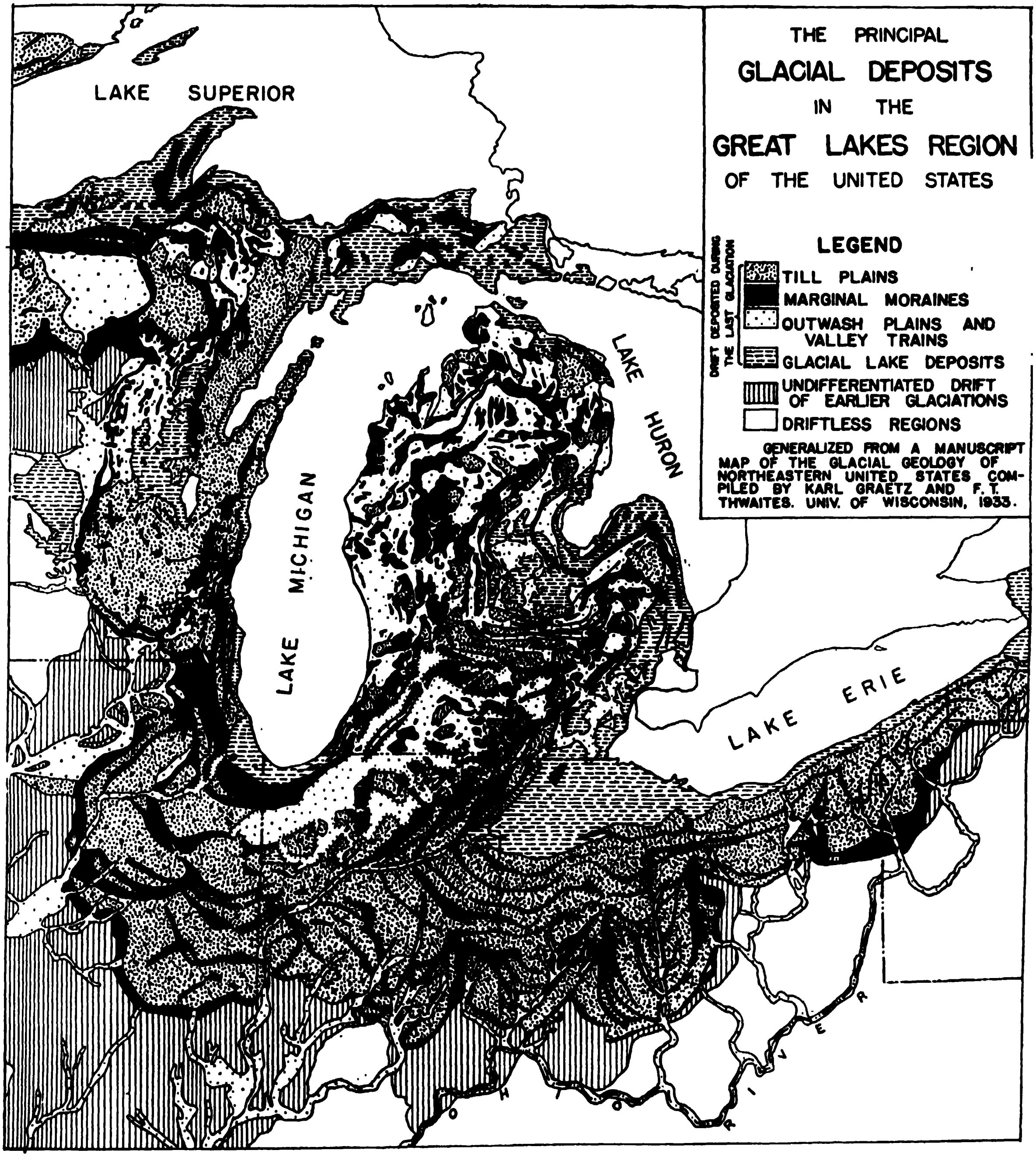


Fig. 211. The pattern of arrangement of the glacial, glaciofluvial, and glaciolacustrine deposits in the Great Lakes region. (*Reproduced by permission of F. T. Thwaites.*)

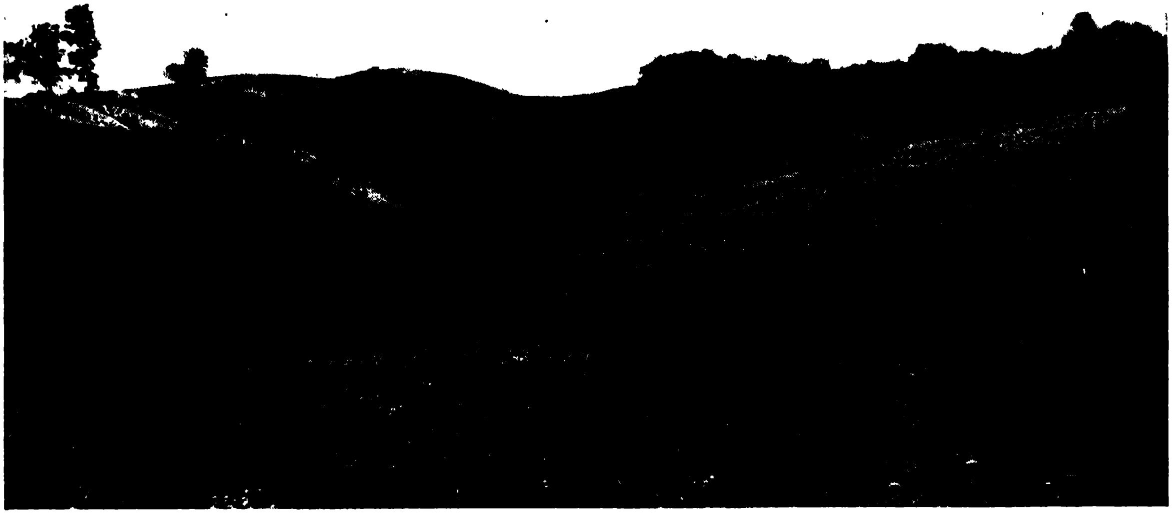


Fig. 212. Two views showing the rough kame-and-kettle surfaces of marginal moraines. (*Photographs by John R. Randall.*)

tended to leave the surface of the morainal ridge much more gravelly and with a higher proportion of large boulders than characterizes the till plain. Even in regions where the adjacent till has not many boulders, marginal moraines may be so stony as to interfere with their cultivation.

442. The Surface Features of Large Marginal Moraines. The rough and knobby surface peculiar to belts of marginal moraine sometimes is called *kame-and-kettle moraine* (Fig. 212). Kames are rounded or irregular hills, sometimes even ridges, of imperfectly stratified glacial gravel. It is believed that they are mainly the conelike or deltalike deposits of streams flowing from the crevassed and more or less stagnant ice front. The more elongated may have been crevasse fillings, while the more rounded were steep alluvial cones formed against the ice front. Some probably were small deltas

deposited in temporary marginal lakes ponded in front of the ice. Being formed of gravelly drift, many of these deposits slumped backward upon the wasting of the ice, leaving mounds of rounded shape and disturbed strata dotting the morainic surface. Kettles are steep-sided hollows, often quite round, in the drift. They are particularly abundant in marginal moraines, where many of them appear to have originated, like many of the lake basins of the till plain, through the separation of large buried blocks of ice from the glacier edge, and their existence there until the glacier was so greatly reduced in extent that the surface depressions caused by the melting of the blocks could not be filled with other deposits.

Not only is the surface of the typical marginal moraine rough and stony, but it is dotted with lakes and ponds which lie in the kettle holes. Lakes of this kind vary from small round ponds to some of considerable size (Fig. 213). Many of them have neither visible inlet nor apparent outlet. They are maintained by surface drainage and by springs in the glacial deposits and are prevented from overflowing by outward seepage through the gravels of the morainic ridge.

Pleasantly irregular surfaces, numerous lakes, and scattered woodlands, left by farmers on steep or stony surfaces, cause belts of marginal moraine to be sought as playgrounds by the inhabitants of adjacent flatter plains.

443. Glaciofluvial Plains. Drainage from a long ice front was discharged through many temporary and shifting streams. Some of them issued from subglacial channels or from crevasses and were large enough to cut wide gaps in the marginal moraines or to prevent the formation of ridges. Often they were overloaded, and escaping from the confines of narrow crevasses or subglacial tunnels, their velocities were checked immediately beyond the marginal moraines. There they built glaciofluvial deposits which have features somewhat like those of floodplains or alluvial fans (379). Some marginal moraines are fringed for miles with *outwash plains* of water-sorted and therefore stratified drift which was washed out from the ice front (Figs. 203 and 214). These are characterized by flat surfaces and an internal structure of rudely stratified sand, gravels, and small boulders (Fig. 215). In general, the clay component of the drift is not present in the deposits because

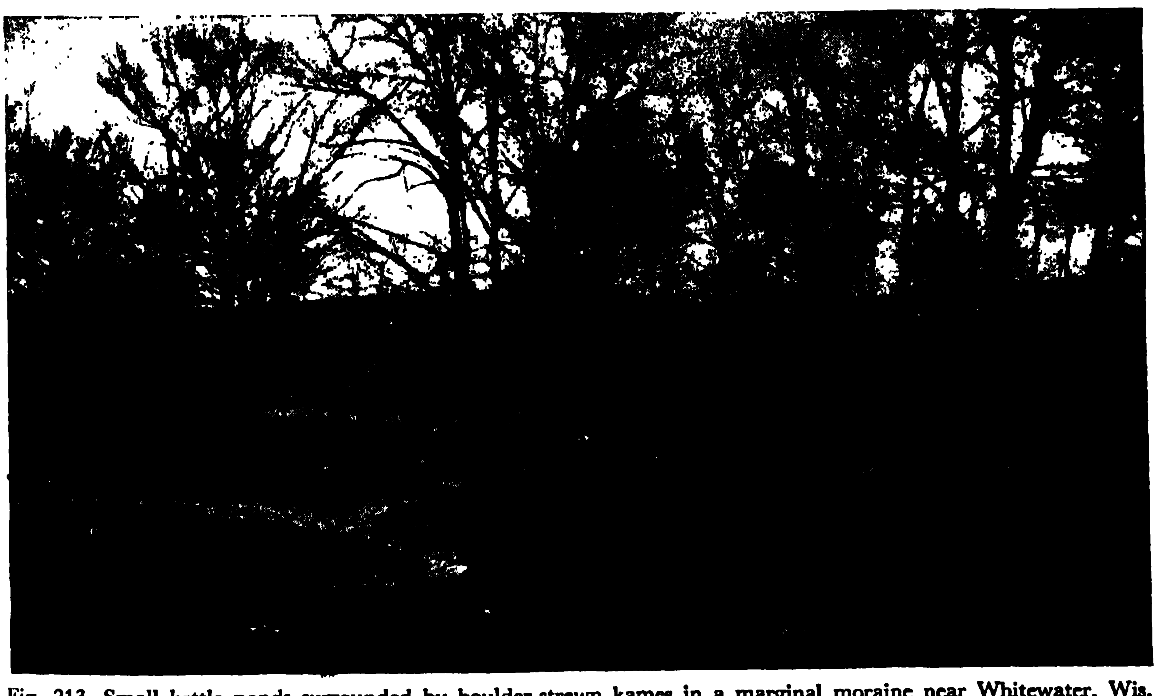


Fig. 213. Small kettle ponds surrounded by boulder-strewn kames in a marginal moraine near Whitewater, Wis.

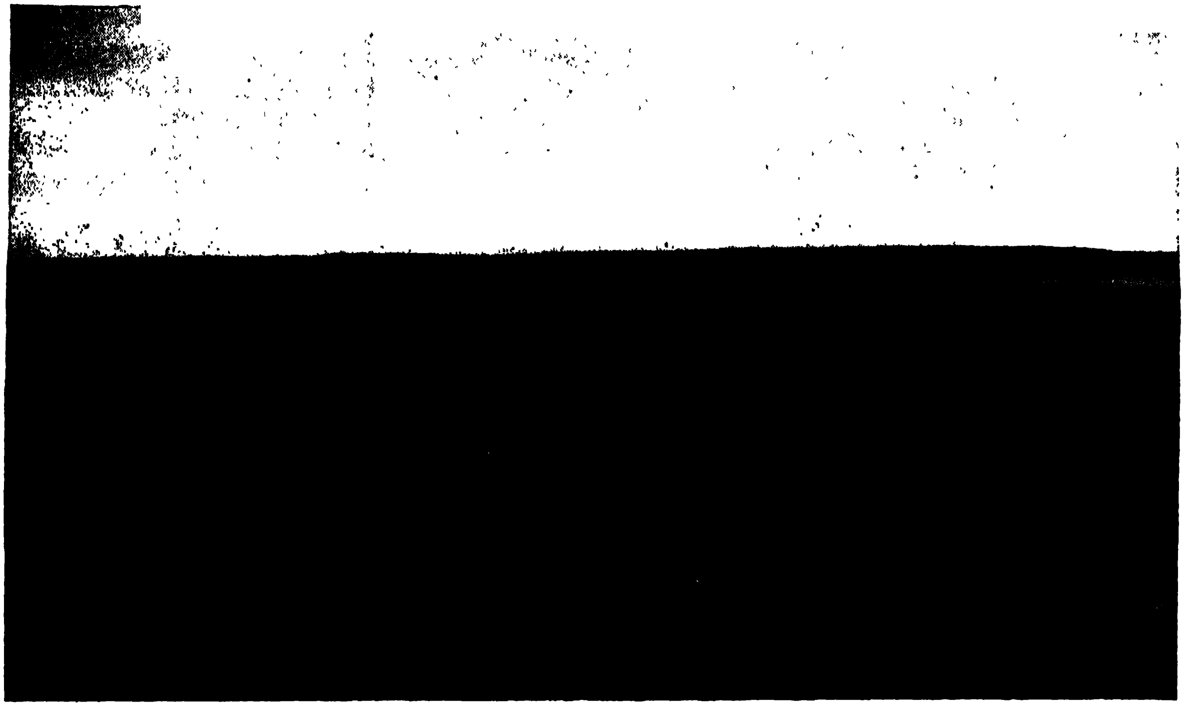


Fig. 214. The flat or gently undulating surface of an outwash plain. (*Wisconsin Geological Survey photograph.*)

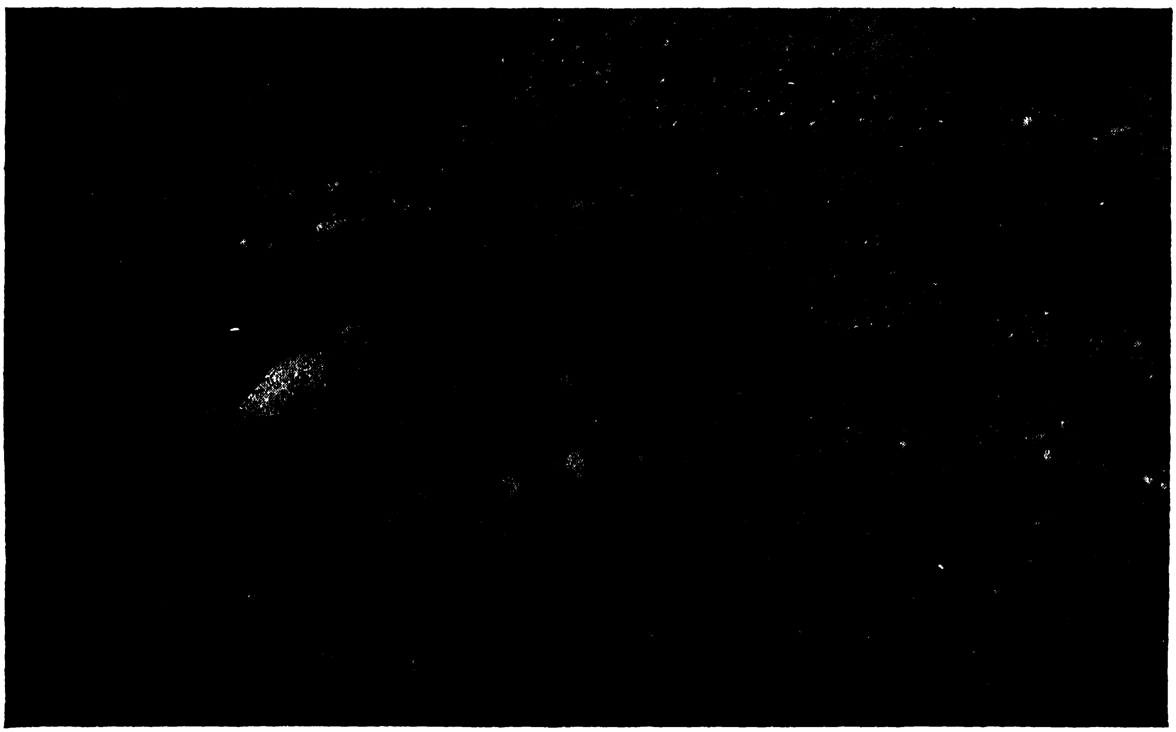


Fig. 215. A cut through an outwash plain showing sand and gravel washed free of clay and rudely stratified according to size. (*Wisconsin Geological Survey photograph.*)

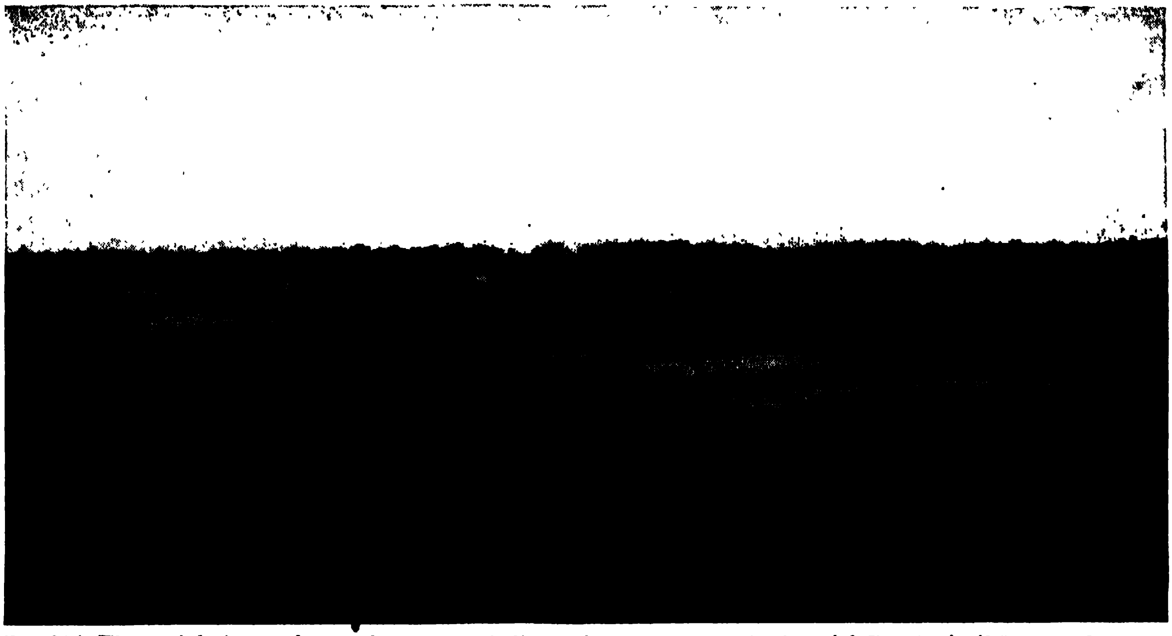


Fig. 216. The undulating surface and numerous hollows of a pitted outwash plain (cf. Fig. 203). (*Wisconsin Geological Survey photograph.*)

it was carried farther on by the streams that built them. The largest boulders, on the other hand, usually were left behind on the moraines. Outwash plains are of frequent occurrence in association with end and other marginal moraines. The generally flat surfaces of some outwash plains that are underlain by till are dotted with kettle holes which appear to have resulted from the melting of stranded and perhaps buried ice blocks left during the glacial wastage (Figs. 203 and 216). Plains of that kind are called *pitted outwash*. They are common among the extensive outwash plains of southern Michigan (Fig. 211). During spring thaws, when the soil still is frozen, the kettles are likely to contain small ponds, but they are not commonly occupied by permanent lakes because of the free drainage of surface waters through the underlying gravels.

Because of the materials of which outwash plains are composed, they commonly are of rather low agricultural productivity as compared with till plains. Even though their surfaces are very flat, they are in some places stony and in others sandy, and usually they are subject to drought because of the free underdrainage. They are, however, provided with naturally crushed and rudely sorted sands and gravels for constructional use, and the supply is abundant since some of the outwash deposits are many feet thick (Fig. 217). The large commercial gravel pits of the Great Lakes region mainly are located in outwash plains.

444. Channel Deposits. The deposits laid down by the abundant drainage from the margin of a stagnant glacier were, in some places, spread fanwise upon outwash plains but in others were confined within definite channels. Some were within the ice; others were beyond its margin. Streams leading away from the fronts of some glacial ice lobes seem to have been heavily burdened, since their channels now are floored with glaciofluvial deposits for many miles beyond the former ice margin. These aggraded glacial stream beds are called *valley trains*, and they bear the same relationship to outwash plains that floodplains bear to piedmont alluvial plains. Valley-train gravels and sands now are found in the floodplains or alluvial terraces (422) of the Mississippi, lower Wisconsin, and other streams the channels of which led away from the front of the great North American glacier (Fig. 211).

Fig. 217. A view showing outwash gravels and marginal moraine in association. The smooth surface of the outwash plain is shown above the gravel pit, and the position of the bordering moraine is indicated by the low hills in the right background. (*The Sheboygan Press.*)

The temporary streams that discharged from the glacier margin flowed under the ice, sometimes at the bottoms of deep crevasses in the ice and sometimes in ice tunnels (Fig. 203). Being heavily loaded, they aggraded their beds and built narrow deposits of glaciofluvial drift within the confines of crevasse or tunnel. If the stagnant ice melted away without sufficient forward motion to erase so fragile a feature, it clearly would remain to mark the course of the ancient stream. Such deposits are not uncommon and are called *eskers*. They appear as sinuous ridges of gravel somewhat like an abandoned railroad grade. Some of them continue, with interruptions, for many miles (Fig. 218). They also are potential sources of gravel for use in construction.

445. The Drift Plains of America and Europe. Those parts of glaciated North America and Europe in which the features made by glacial deposition predominate over those that result from ice scour are roughly indicated in Figs. 219 and 220. Not only are the drift plains extensive, but they include a large part of the most populous and highly developed sections of those continents. Also, by reason of the strong contrasts possible in the surface forms, composition, and drainage of drift, they contain localities of very different appearance and utility. There are poor areas, such as the Northwestern Pine Barrens of Wisconsin or the Lüneburg Heath of Germany. There are productive areas, such as the plains of eastern England or those of western Ohio. Each of the regions of continental glaciation has its areas of lake-dotted marginal moraine and its areas of till plain with drumlins, marshes, and undulating cultivable lands. However, in the drift plains of both continents are some contrasts which cannot be explained in terms of local variation of glacial action or of underlying rock.

446. New Drift Plains and Old. The characteristic features of drift plains, as they were described above, are mainly those of glacial

Fig. 218. A narrow sinuous ridge of the esker type. It contains glaciofluvial drift and may have been deposited in an ice tunnel or in a crevasse. (*Photograph by John R. Randall.*)

deposits so recent that they have been little altered by weathering and erosion since their deposition. There are associated with them, in both North America and Europe, extensive plains which bear unmistakable evidence of being ice deposited but which clearly are much older (381). The gradational processes have been so long at work upon them that they have reduced some of the irregularities and created new ones. Morainal ridges have been subdued, kames worn down, kettles filled, and lakes drained or filled, so that the number and irregularity of these features are much less than in the newer drift. Erratic boulders have been weathered until many of them crumble into earth, and gravel deposits have been disintegrated or buried beneath later alluvium or deposits of loess (462). The result of these changes has been to produce more gently undulating plains, better drained and with finer and more uniform drift. On the other hand, the greater age of this drift has permitted erosional features to develop which locally increase the irregularity of the surface. The aimless pattern of the drainage characteristic of new drift has been reformed and approaches the dendritic pattern of stream-eroded plains. Stream valleys have been cut through the drift into underlying rock. In places the drift is largely removed and becomes thin or patchy, so that the surface features are not greatly different in appearance from those of the driftless plains beyond the margin of former glaciation. Even marginal moraines are so changed that the former positions of some of them may be conjectured only from remnants. The distribution and comparative extent of the new and older drift sheets of America and Europe are indicated in Figs. 219 and 220. In America the older drift is found over large areas in the undulating plains of southern Illinois, northern Missouri, and in parts of Iowa, Kansas, and Nebraska.

447. The Older Drift Subdivided. In the older drift itself students of glaciology recognize drift horizons of several distinct ages. These are separated by layers of plant remains and other evidences of great lapse of time. While the latest of them is far older than the newer drift, it may be noted that even the oldest of them is much younger than the sedimentary rocks upon which they rest. This can lead only to the conclusion that, however many thousands of years

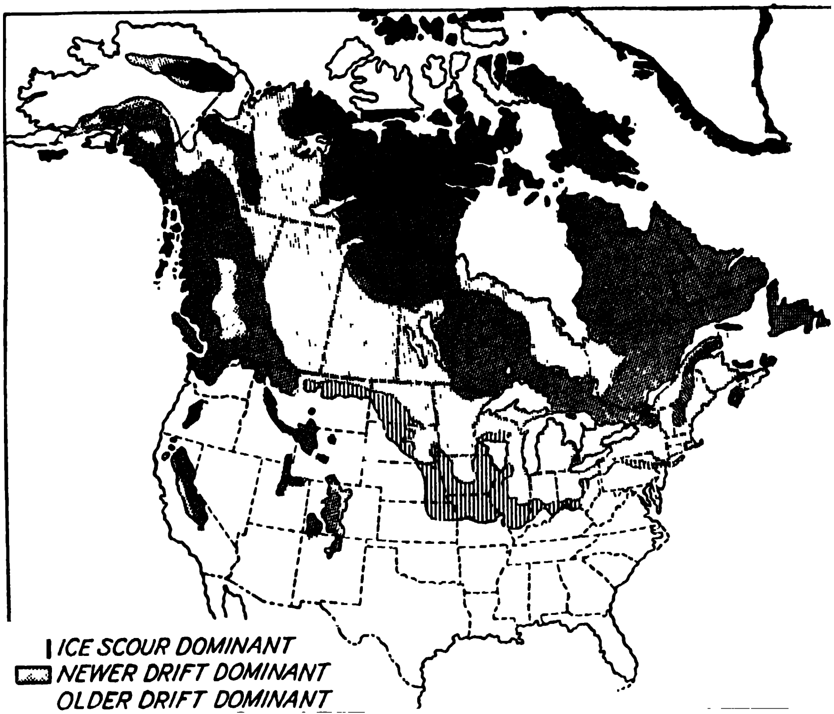


Fig. 219. The glaciated regions of North America distinguished as to the dominance of older drift, newer drift, and ice scour.

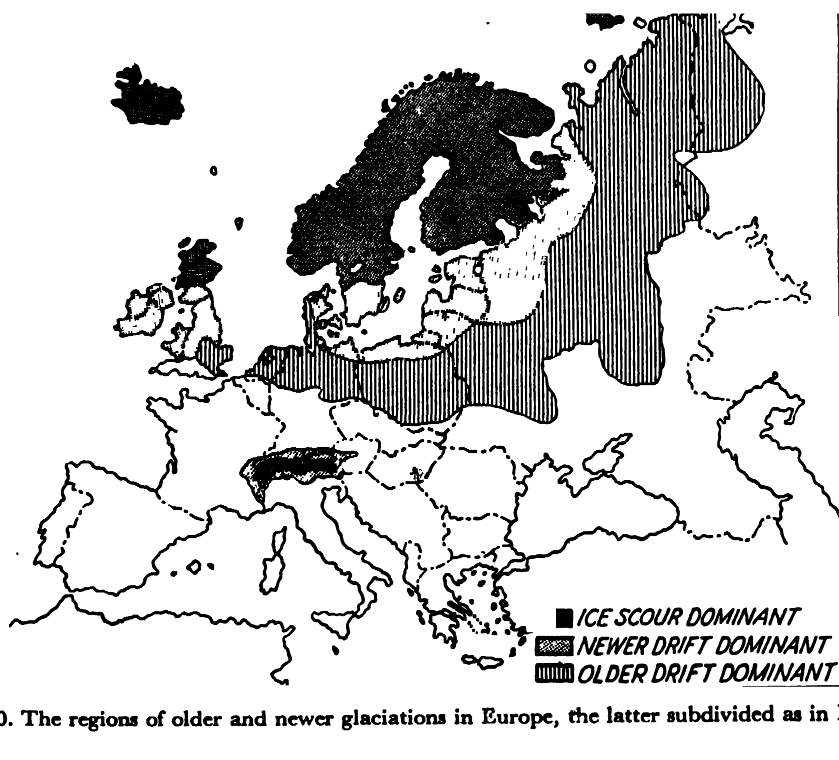


Fig. 220. The regions of older and newer glaciations in Europe, the latter subdivided as in Fig. 219.

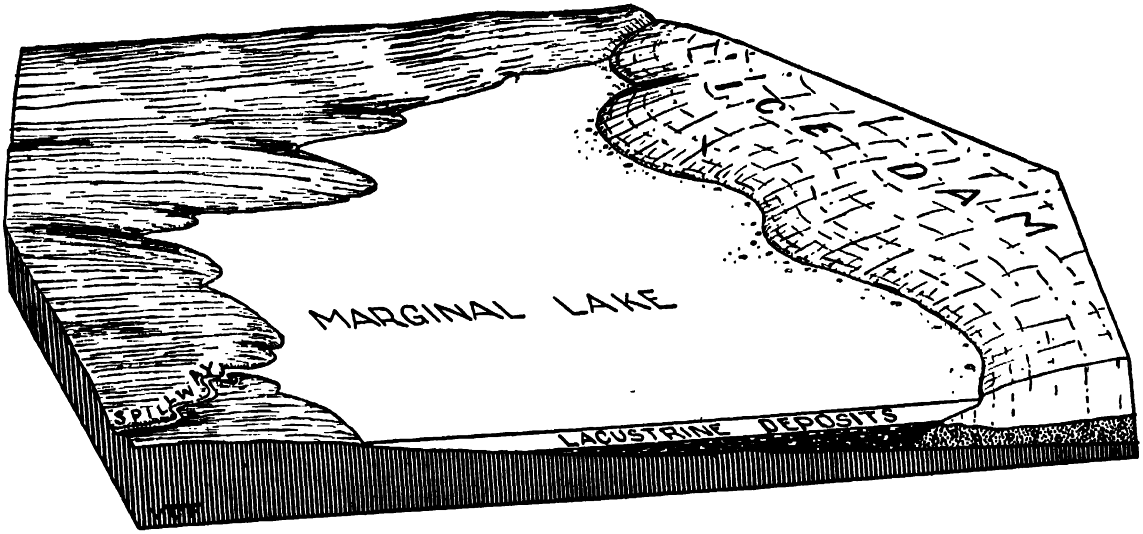


Fig. 221. A diagram to illustrate the formation of a temporary lake between the margin of a glacier and a low divide across which the surplus drainage escapes. Glaciolacustrine deposits are seen in the lake bottom.

it may be since the disappearance of the last ice sheet, it is many times that number since the coming of the first one. Also, that the "ice age," including all the several periods of glacial advance and wastage with intervals between them, is but a relatively recent event in earth history (see Appendix E).

448. Glacial Lakes and Lake Plains. It has been shown how glacial lakes have been converted into marshes and the marshes into farm land by filling or by draining through natural processes or human intervention. Thousands of small flats of that kind are found among the farm lands of drift plains. Somewhat different in kind, and of immensely greater size, are a few plains resulting from the existence of former great lakes now diminished in area or completely disappeared. It has been observed that the lakes of the drift plains are due to some kind of glacial obstruction of present drainage. This is in some degree true even of the Great Lakes. However, in an earlier stage in their history the drainage of the Great Lakes, and of several other large lakes which have now disappeared, was obstructed by the ice of the glacier itself. Where the ice front rested upon a surface that sloped down toward the glacier it furnished drainage that could not escape and, therefore, was impounded in a lake that had the ice front as one margin. The lake rose until it found an outlet at the lowest point on its rim (Fig. 221). Temporary former glacial lakes of that kind are known as *marginal lakes*. The final wastage of the ice barrier back of a marginal lake removed the obstruction that caused it. The drainage sought a new and lower outlet, and the lake dwindled in size or disappeared entirely. During the periods of their existence marginal lakes modified the land surfaces that they covered and in their disappearance left behind unmistakable features which are called *lake plains* or *lacustrine plains*. Their distinguishing features are level surfaces which are comprised largely of the wave-worked ingredients of the drift, silts and clays where they were abundant, but sometimes sand also (Fig. 222). Plains of this origin have a flatness similar to that of newly emerged marine plains. There are few extensive plains more level than these (Fig. 223). They include also shore features such as abandoned beach ridges, offshore bars, and deltas that are comprised largely of glacial sands and gravels. These features are spread at intervals that mark successive stages in the lowering of the outlet and the decrease of the lake area.

Many of the areas shown in Fig. 211 to be lake plain, such as parts of the Upper Peninsula of Michigan, had surfaces too rough to be com-

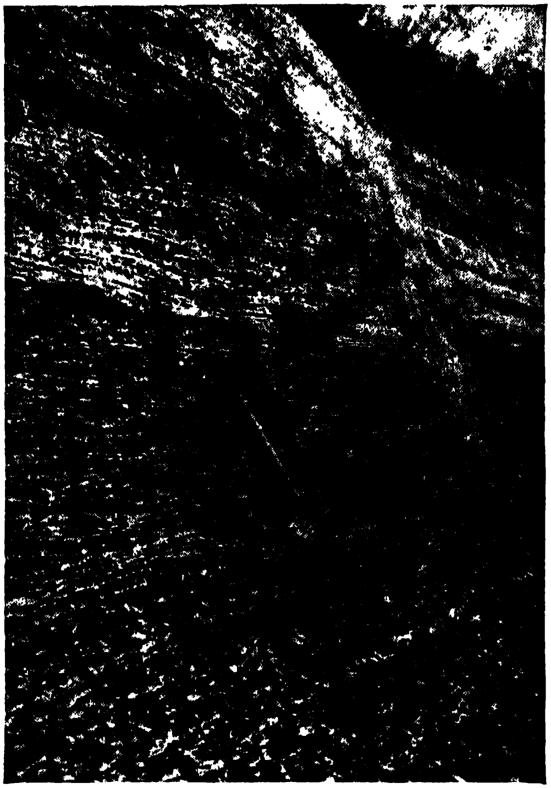


Fig. 222. A present exposure of finely stratified or *varved* clays which accumulated in the bottom of a temporary lake of the glacial period. (*Wisconsin Geological Survey photograph.*)

pletely submerged by the temporary lakes of glacial times. They now contain areas of lake plain interspersed among rocky hills. Many of the latter, during the existence of the enlarged lakes, must have been islands. In places also, stream erosion since glacial time has dissected the lacustrine plains so thoroughly that only remnants of their flat surfaces now are to be seen.

449. Notable Lacustrine Plains. Glacial lake plains are found in Europe, and there are in America several of great extent and unusual economic significance. Notable among these are the lake-plain margins of the present Great Lakes, the Lake Agassiz plain, the southern part of the Ontario Clay Belt, and the sand plain of central Wisconsin. During certain stages in the wastage of the last ice sheet the southern portions of the Great Lakes were exposed while the great ice dam still lay across the lowest and present outlet through the St. Lawrence Valley. Drainage from the ice front during that time was forced to seek other and higher outlets. This caused the formation of lakes of larger area than those of the present. The bottoms of those more extensive lakes, containing the unleached glacial silt and clays, are now flat and fertile plains in northern Ohio, eastern Michigan, western New York, and elsewhere (Figs. 224 and 211). Even the city of Chicago stands in large part upon one of them. They are bordered by a series of beach ridges and other shore features which mark the lake levels at the stages of successive outlets. These slightly elevated ridges were occupied by prehistoric Indian trails and were much used as thoroughfares in the days of early settlement because they were well drained. Several are now the sites of important roadways established at that time. Examples of such roads are seen in U.S. Highway 31 west of Rochester, N.Y., and U.S. 20 both east and west of Cleveland, Ohio.

In the same manner glacial drainage was impounded in a large marginal lake between the wasting ice front in central Canada and the higher land of central Minnesota. A broad and shallow lake created upon this slope found for a long time its lowest outlet through the course of the present Minnesota River into the Mississippi. The wave-worked sediments that were spread over the floor of that formerly extensive body of water, which is known as Lake Agassiz, now comprise the flat and fertile Red River Plains. Lakes Winnipeg and Winnipegosis now occupy the lowest portions of the depression, the remainder of the lake having disappeared when the ice dam was removed.

Upon the ice-scoured surface of the Laurentian Shield where morainic deposits generally are scant, coarse, and infertile is a region known as the Ontario Clay Belt. It is a district of growing agricultural value and is comprised in part of sediments laid down in a marginal lake. So also is the plain of central Wisconsin, but in this instance both the drift from which the sediments were derived and the lake bed upon which they were deposited were composed largely of sand-

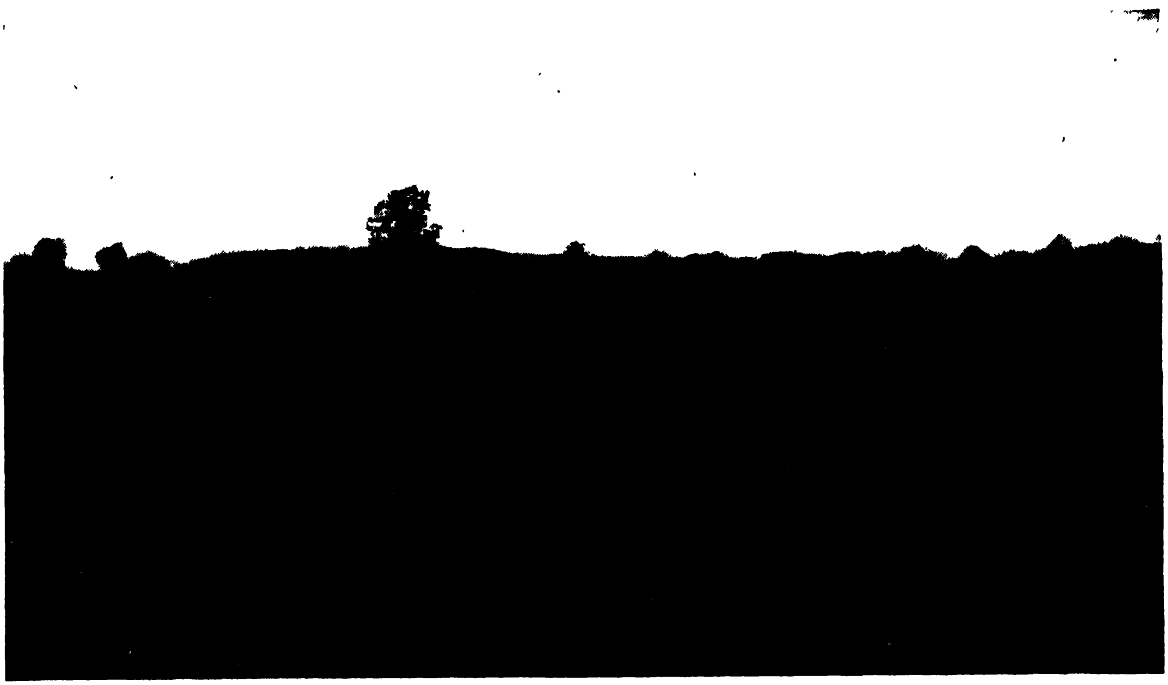


Fig. 223. The extremely level surface of a glacial-lake plain near Saginaw, Mich. (cf. Fig. 211).

stones. The lake plain of central Wisconsin is therefore flat but not fertile.

450. Important Glacial Spillways. Summer melting along an extended ice margin must have produced large volumes of drainage water. It would be strange if streams of sufficient size to carry so much water had not left their marks upon the landscape. The principal marks are ancient spillways. These are broad valleys eroded in the drift or in rock beds where ice-front or marginal-lake drainage cut across low divides into established rivers leading to the sea (Fig. 225). Many such spillways are known, both in America and in Europe. Several of them are now occupied by streams that seem ridiculously small in valleys that appear to have been eroded by streams of the size of the Mississippi. Figure 224 shows the location and drainage relationships of the principal American spillways. It will be recognized at once that some of them are of unusual significance as routes of present-day transportation. The Chicago outlet provided a naturally graded site which made possible the economical construction of the Illinois and Michigan Canal and later the Chicago Sanitary and Ship Canal. It is traversed also by railway lines and an important highway. The Mohawk Valley outlet toward the Hudson River furnishes the lowest and best graded route across the Appalachian Highland. It became a busy thoroughfare after the construction of the Erie Canal through it and now carries a high concentration of rail and highway traffic. The

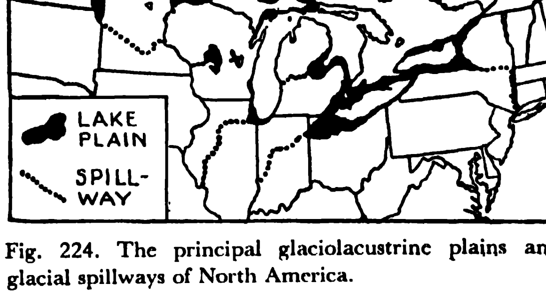


Fig. 224. The principal glaciolacustrine plains and glacial spillways of North America.

modern reclamation project in central Washington makes use of the Grand Coulee, an abandoned channel resulting from the glacial diversion of the Columbia River. There are numerous other abandoned channels in North America, such as those along the upper Missouri and Mississippi Rivers, and in northern Indiana, central Michigan, southern New York, and elsewhere. Figure 226 shows the network of spillways which carried drainage from the wasting ice fronts at various stages in the deglaciation of Europe. The channels made by that drainage cut across the present trend of the river valleys of the North European Plain and provide natural access from one of them to another. The German system of canals utilizes these graded courses to link together the natural waterways of the country.

Fig. 225. The flat-bottomed channel of a former glacial spillway, not now occupied by any stream. (*Wisconsin Geological Survey photograph.*)

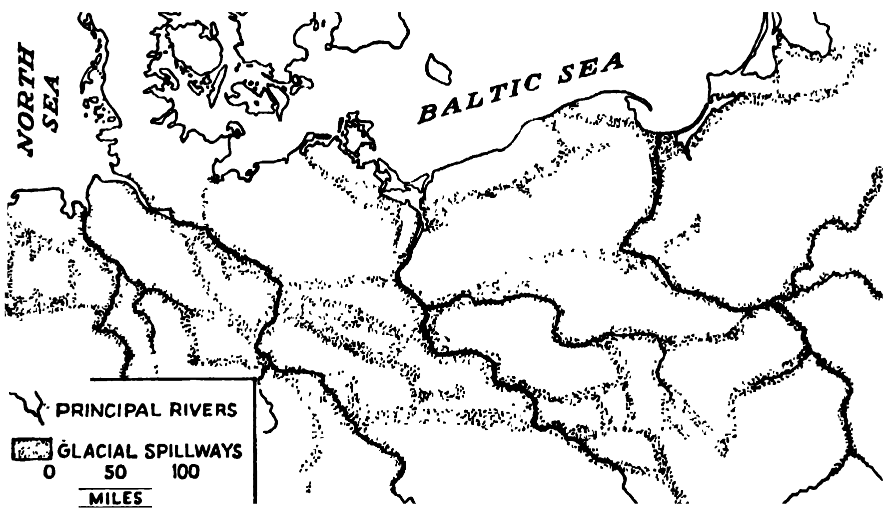


Fig. 226. The glacial spillways that drained the long European ice front toward the west at its various stages of disappearance. (*After Paul Woldstedt. Das Eiszeitalter.*)

CHAPTER 17: *Plains in Dry Climates*

Desert Plains

451. It may be assumed that the features of arid desert plains result from the operation of the same tectonic and gradational processes that have been considered in connection with the features of other plains. However, the features of arid plains do not look like those of plains in humid regions, because the work of the gradational agents under arid climates is sufficiently different so that many distinctive features are produced. The outstanding differences between the features of arid-land relief and those of humid regions may be attributed largely to the following: (*a*) the much slower rate of weathering in arid regions than is found under humid conditions; (*b*) the meagerness of the vegetative cover of desert surfaces, with resultant lack of protection against erosion; (*c*) the intermittent but typically rapid runoff of desert streams; (*d*) the peculiar and highly selective nature of desert-stream erosion; (*e*) the prevalence of basins of interior drainage; and (*f*) the widespread occurrence of features that result from wind erosion or wind deposition. So general is the distribution of the latter that arid plains might almost be called aeolian plains.

452. Features Resulting from the Slowness of Desert Weathering. Both chemical and mechanical weathering act upon the rocks of desert regions, but owing to infrequent precipitation and low atmospheric humidity they act slowly. The rate of erosion is rapid by comparison, since both wind and flood waters are active eroding agents. The slowness of weathering and the comparative activity of erosion result in the exposure of unweathered rock features in bold outlines and sharp details which, in humid climates, would be softened in contour by rock decomposition, by soil creep, by slumping, or by burial underneath an accumulation of weathered debris. For that reason, and because there is so little vegetation to conceal them, fault scarps, the eroded edges of sedimentary strata, or stream-eroded bluffs commonly stand out prominently upon the desert plain. Even small features fail to lose, in spite of long exposure, that angularity of profile and freshness of detail that make them appear to be of recent origin (Fig. 227).

453. Features Resulting from the Peculiarities of Desert-stream Erosion. In humid plains the streams that result from well-distributed rainfall and the addition of ground water through springs and seepage flow steadily and cut valleys the forms and patterns of which have become familiar. In arid regions most streams are intermittent, but occasionally they flow in great volume as a result of the fall of torrential rain upon the bare surface of earth, which is parched and incapable of absorbing moisture rapidly. Under these conditions, according to Johnson,[1] the intermittent streams have a tendency to acquire a load quickly by downward erosion at their headwaters in the bordering highlands, while in their middle courses on the plains they tend to choke their own channels, build sand bars, and subdivide into many shallow, braided channels in which occasional torrents of water spread and shift from side to side. Instead of cutting greatly downward in their middle courses desert streams tend therefore to swing laterally, undercut the edges of bordering elevations, and plane

[1] Douglas Johnson. Rock Planes of Arid Regions. *Geog. Rev.*, Vol. 22, pp. 656–665, 1932.

Fig. 227. The steep undercut banks of a desert-stream channel in Arizona. The stream, here easily forded, sometimes is a flood that occupies the entire channel. The small embankments beyond the automobile mark the heights of lesser floods. (*Photograph by De Cou. From Ewing Galloway.*)

them off, leaving the eroded surfaces covered only by a veneer of alluvium. It is a kind of erosion that is not widely developed in humid regions.

One consequence of the arid-land type of erosion appears to be the formation of relatively smooth rock floors, usually covered by thin veneers of gravel. Such limited plains are found as belts about the margins of many desert mountain ranges, from which they decline outward. They are bordered on their upper margins by the considerably steeper slopes of the mountains, and on their lower margins they disappear gradually beneath thicker alluvial deposits. These rock plains have been called *pediments.* On some of them, at intervals, are islandlike hills of rock which appear to be remnants of the original mountain mass that have escaped planation. Although the construction of a pediment appears to begin in the graded middle courses of the streams flowing from the mountain, the process creeps upslope as the valleys get older. Lateral stream erosion, wind abrasion, and possibly springs and seepage gnaw at the bases of the foothills and spurs, and ultimately the eroding surface of the plain extends into the mountain mass itself (Fig. 228). Finally the highland may be eroded entirely away during the progress of the cycle of erosion.[1] The pediment is, therefore, a type of small rocky plain peculiar to the desert, and examples of it are known in several arid plains. They are abundantly developed about the mountain ranges of the North American desert (Fig. 229). In the Sahara are broad expanses of rocky desert plain, some of which are 100 to 200 or more miles across. Some of them are believed to be parts of ancient peneplains which perhaps are the remnants of still more ancient highlands baseleveled by desert erosion. If this is true,

[1] Eliot Blackwelder. Desert Plains. *Jour. Geol.*, Vol. 39. pp. 133-140, 1931.

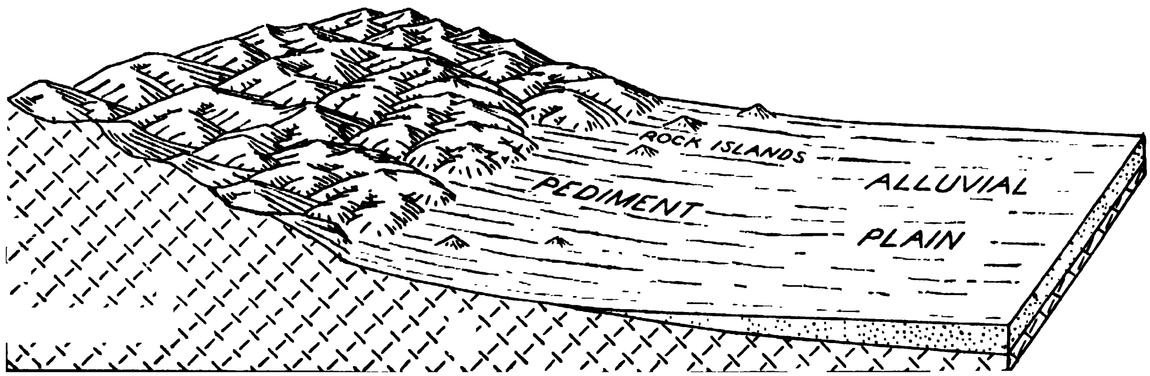


Fig. 228. A diagram to illustrate a pediment bordering a hill region and extending beneath an alluvial plain. Within it are several rock islands which are erosion remnants.

Fig. 229. The long-eroded slope of this pediment, which borders one of the basin ranges of Nevada, has a veneer of desert alluvium. (*Photograph by John C. Weaver.*)

then they are fully developed pediments which have been slightly elevated in more recent geological time, stripped of their alluvial veneers by the work of wind and water, and gashed by steep-sided stream channels, now dry.[1] Having little soil, these rocky plains have little even of desert vegetation, and they are the most completely desert of all arid plains. In northern Africa they are called *hamada*, and the term may well be applied to similar rock plains in other deserts.

The effect of sidewise erosion of the dry-land type in regions of horizontal sedimentary strata is seen also in flattish surfaces that are not necessarily baseleveled. By lateral cutting, less resistant formations are stripped away down to the surface of a more resistant stratum the surface of which then practically coincides with the surface of the plain. Such plains are called *stripped plains*. The effect of lateral cutting also is manifest in the transverse profiles of stream valleys in arid plains. Where valleys of considerable size have been cut in desert plains, they commonly are steep-sided and flat-bottomed and clearly are being widened by slumping of the valley walls (Fig. 227). The valley walls are not only steep, but because of the scarcity of surface drainage, they commonly are rela-

[1] E. F. Gautier. The Ahaggar: Heart of the Sahara. *Geog. Rev.*, Vol. 16, pp. 378–394, 1926.

tively little dissected by gullies and are therefore sharp-rimmed and of bold outline. There are tributary valleys, but they have similar profiles, and the result is the dissection of the upland into flat-topped, or tabular, blocks which are separated by flat-bottomed valleys. The slopes between upland and lowland are steep, and lateral erosion, coupled with a slow rate of weathering, tends to keep them so.

Many desert plains have dry valleys of the flat-bottomed, steep-sided form.[1] Some of them are utilized as routes of travel because they furnish well-graded paths across otherwise dissected uplands. Upon their bottoms seepage water and soil water stored from the latest rains suffice to support more forage for beasts than may be found upon adjacent uplands. In the dry stream channels natural water holes or the digging of shallow wells may provide drinking water at usable intervals. In some desert valleys there is a sufficient supply of spring or well water in favored spots to provide for a limited irrigation of crops. Such spots are the sites of another kind of oasis (418, 425).

454. Alluvial Basins of Interior Drainage. In many arid plains are structural (tectonic) basins into which are discharged the drainage waters of the plain and with them great quantities of alluvial filling. In humid lands streams that flow into structural basins fill them with water, creating lakes which overflow the lowest point upon the rim, and the drainage ultimately reaches the oceans. Few streams in arid plains have sufficient volume or permanence to flow to the ocean. They flow intermittently and sometimes with great volume, only to be swallowed up in the desert floor or to spread in shallow lakes over the lowest parts of their basins, where exposure to sun and dry winds soon evaporates them. Flood water, therefore, moves toward the center of the basin, but none flows out. For that reason the desert plain may be said to be typically a region of *interior drainage*. Only a few streams, those of greatest volume and permanence, and especially those exotic streams that derive most of their waters from highlands beyond the desert, are able to flow across it and reach the sea. Only for the great streams is baselevel determined by sea level. For the others it is determined by the levels of the alluvium-filled basins or temporary lakes into which they flow (368).

455. The Drainage of Desert Basins. The basins of desert plains generally are broad and shallow features. Within them lie accumulations of alluvium which aggrade and flatten the basin floors. Upon the flanks of some, especially the smaller and deeper ones, the filling is collected in the form of encircling alluvial fans. Basins of that type have been called *bolsons*.[2] In many of the shallower basins the alluvium is spread uniformly over the gently sloping plain. The lowest portion of the typical basin of interior drainage shows evidence of concentration of drainage there in the form of marshes or lakes. If the general rate of inward drainage is balanced by the average rate of loss through evaporation, a lake is likely to exist. It will be a salt-water or alkali lake, because water is continually removed from it by evaporation while the salts contained in the inflowing water, especially the common salt, remain behind in solution and eventually reach concentrations that make some salt lakes more salty than the oceans. If the rate of evaporation generally is in excess of the rate of inflow, temporary, or *playa*, lakes will result from occasional torrential inflows of water. These are followed by periods of excessive evaporation. The marshy beds of these ephemeral lakes commonly are mud-covered and are strongly charged with salt or soluble soil alkalies.[3] When thoroughly dried they commonly are incrusted with salts and sometimes are glistening white in color (Fig. 230). In this class of deposits are not only those of common salt and other compounds of sodium and cal-

[1] In America the Spanish name *arroyo* is the term most commonly applied to small stream channels in the dry lands. The Arabic term *oued*, or *wadi*, is used for similar features in the Saharan region.

[2] The term *bolson*, a Spanish word meaning a large pocket, was applied originally to mountain-rimmed basins of interior drainage. Its meaning is here extended to all basins of interior drainage in dry lands.

[3] In America these features are called *alkali flats*. Similar features in other deserts are known by various names, such as shotts, vloers, vlei, and salt pans.

Fig. 230. A playa basin in Nevada. Its deep alluvial filling has a glistening white crust of salt, and wind-blown salt clings to the rock island included within it. (*Photograph by John C. Weaver.*)

cium, which are called *alkali*, but also some of economic value. Among the latter are the borax deposits of southwestern United States and the famous sodium nitrate deposits of northern Chile (723).

The great salt lakes of the world lie, as may be expected, in basins of internal drainage, some of which are plains of great size. Noted salt lakes are the Aral and Caspian Seas, which are surrounded by the plains of Russian Turkistan; and Lake Eyre in southern Australia. The latter usually is a dry salt plain and its level is, like that of the Caspian, lower than sea level. Great Salt Lake and several other permanent salt lakes also are situated in basins of interior drainage but at such elevations above sea level that they may be considered in connection with plateaus.

456. Features Resulting from Wind Erosion. The sparsity of vegetation in arid plains regions gives unusual scope to the erosional activities of the wind. Some of the minor landforms show abundant evidence of the abrasive effect of wind-blown sand. Wind abrasion aids differential weathering in the production of curiously etched, rounded, or polished details of rock surface, some of them in fantastic shapes. Of much more widespread importance than this minor activity is the general process of *deflation* (386). Dust and sand are removed from all parts of the desert surface but perhaps most abundantly from the lower portions of interior drainage basins, where the material is generally finer. This process has the effect of deepening the basins which otherwise tend to be filled by alluvium. It is the only means by which earth may be removed from the basin of interior dra ıge.

457. Deflation and the deposition of the products of deflation result in the formation of a number of significant dry-land features. Upon the margins of desert basins it is less effective in the removal of material because the material there usually is more coarse and rocky. The surfaces of pediments yield little that wind may transport, and the upper margins of fans are made up of the coarser stream-transported materials. Such fine material as exists or is provided by local weathering is quickly removed, leaving behind the fragments that are too heavy for wind removal. These remain until they cover the surface, forming what is called a *desert pavement* (Fig. 231). In some regions the pebbles and fragments of the desert pavement are covered by a thin coating of iron oxide and

other chemicals which is polished by dust abrasion to a glossy surface called *desert varnish.* They color the plain with glistening yellow, brown, red, or even black. In those parts of a desert plain which are deeply covered with alluvium, deflation removes the finer surface material, leaving a gravelly desert pavement, underneath which is fine alluvium. Because of their deeper soils such areas hold more moisture than the rocky hamada and are likely to have a little more vegetation. Great expanses of flat, pebbly or gravelly, alluvial, desert plains of the kind just described are, in Sahara, called *reg*.

In the central portions of large desert basins of alluvial filling the deposits are less coarse and more subject to deflation. Dried and crumbled playa muds are unprotected by vegetation and are easily removed. Under intense insolation dancing whirlwinds lift dust high into the air and not only transport it, but may even remove much of it entirely from the basin to regions well beyond its borders. It is probable that the total thickness of surface material thus removed from the floor of the desert basin is great enough to be an important factor in maintaining the basin shape.

458. Aeolian Sand Plains. From the foregoing it is clear that the popular conception of the arid plain as a sea of wind-blown sand is not well founded. Not many large desert areas are so much as one-fourth sand covered. However, there are many regions of sandy desert. The abundant rock grains in them are derived (*a*) from the disintegration of sandstone and other bedrock in the locality where the sand deposits are found or (*b*) from local accumulations of transported fragments separated by wind sorting from both the finer and the coarser products of rock weathering elsewhere. The finer weathered particles, removed as dust, are whirled high into the atmosphere, carried entirely away, and deposited as loess far beyond the limits of the region. The coarser fragments remain behind as components of the desert pavement. The sand, however, is carried in the lower atmosphere, transported to considerable distances, and lodged in quantity, often in the form of sand ridges or sand dunes, on sites so sheltered as to have reduced wind velocities or in some other way to favor the accumulation of sand.

459. *The Features of Sand-ridge and Sand-dune Areas.* Sand plains are of some extent

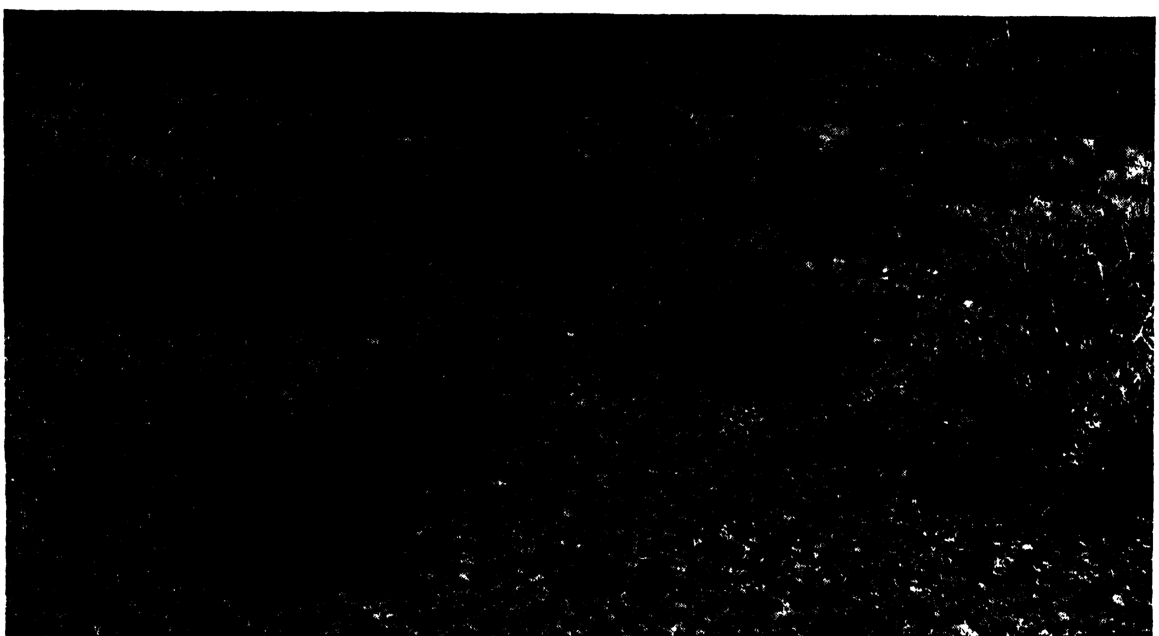


Fig. 231. The pebbles and rock fragments of a desert pavement in western Nevada. (*Photograph by John C. Weaver.*)

and vegetation. Yet that is not true of all of them. Even light rains sink readily into the porous sand hills, where the water is stored and yielded in favorable sites to springs or wells. In western Sahara some of the notable oases lie in the midst of great dune areas. Some of them are located in series on favored sites along old desert stream channels which have been overrun and largely buried by migrating dunes. In the buried channel sufficient water concentrates by seepage to supply irrigation to restricted basins among the dunes. In these still another class of oasis may be recognized, highly important locally but generally of small size and much less significant than the principal classes previously noted (418, 425, 453). Even where there is not sufficient water for irrigation, not all dune areas are devoid of vegetation. Within the pockets and basins among the dunes, seepage of rainwater is sometimes able to provide the basin floors with sufficient moisture for the growth of pasture. Sand-dune grazing areas of that kind are found in the desert regions of all the continents, including those of the United States. Among the sand hills of Nebraska are many ponds or pools where livestock can obtain water or depressions where the ground-water table is so near the surface that shallow wells equipped with windmills can provide water for that purpose (Fig. 233).

Loess Plains

461. The Features of Loess Plains. Some of the considerable plains of the world are loess mantled (387). Not all loess deposits are plains, because aeolian dust comes to rest upon hill and valley alike and is found in regions of great relief as well as upon lowlands. The thick loess mantle that covers the rough surface of northwestern China has been much eroded also and in places is of extreme irregularity. Elsewhere are loess deposits which, if not so deep as those of China, are of equal or greater area. Some of these are found upon extensive plains, but they are not in themselves the cause of the plains. They merely cover and perhaps increase the levelness of plains due to other physiographic causes.

462. The Nature and Distribution of Loess. The dust of which loess is composed is fine, but it is chemically undecomposed. Its character indicates accumulation by wind transportation over distances great enough so that coarse material is not included with it. Its unleached condition indicates also that the material is derived from sources in which mechanical rather than chemical weathering is predominant. Such sources are found in, and the loess deposits are believed to have been derived from the deflation of, (*a*) arid lands and (*b*) the bare drift deposits and abundant stream muds which were associated with the retreat of the former continental ice sheets.

Loess deposits are deepest and most widely distributed in regions of steppe environment because, generally, those regions border the deserts, and because there the soil is sufficiently moist to support a grass cover so that the loess, once deposited, is not easily removed again by the wind. In central United States and central Europe the principal loess deposits are believed to have been derived, at least in large part, from the muds of the fresh drift and the drainageways associated with the wastage of the former continental glaciers. Loess of that origin is found well beyond the borders of the steppe regions and even to some extent in regions of humid climate and forest vegetation. The internal structure of loess is unstratified, highly porous, and characterized by fine vertical tubes which probably are related to the existence of former plant roots. Owing to its structure it has the property of standing in vertical faces when cut through by streams or roadways, even though the material is so soft as to crumble to dust when pressed between the fingers (Fig. 234). Unweathered minerals, porous structure, fine texture, and high water-holding capacity help to explain the reputation for high fertility held by loessial soils.

463. The Great Loess Plains. Because loess plains underlie some of the most productive agricultural regions of the world, attention may here be directed to the situations and characteristics of several of them.

Fig. 234. A recent road cut through a loess hill in the prairie region of eastern Nebraska.

North America. Loess is an important surface component over a large area in interior United States. It is particularly abundant in association with parts of the older drift, especially the western margin of the area of older glaciation and the drainageways leading from it (446). There the raw glacial deposits appear to have been subject to deflation for thousands of years under semiarid climatic conditions. In a few places only are the deposits so deep, so unchanged by weathering or stream work, so continuous, or so extensive as to constitute what properly may be called loess plains. The deepest accumulations are found in the plain that includes southern and eastern Nebraska and about the western one-fifth of Iowa (Fig. 235). There the loess in many places reaches a thickness of 60 to 100 ft. Since the Missouri River valley traverses this region there are numerous exposures of eroded vertical loess walls along its bluffs, as, for example, at Council Bluffs, Iowa. The border zone, which has been dissected by small streams tributary to the Missouri, also has valleys of a peculiarly abrupt and steep-walled type. The loess-mantled uplands are of undulating surface. Other deep and extensive accumulations of loesslike earth cover much of eastern Iowa, adjacent parts of Wisconsin, central Illinois, and extend down the eastern bluffs of the Mississippi River. These generally are less deep than those of the Missouri River region, but locally they attain great thickness (Fig. 236). Still another notable deposit of loess occupies a part of the rolling plateau of eastern Washington and Oregon, where it buries the lava surface.

Dust storms are not unfamiliar phenomena even now in the High Plains and Mississippi Basin. The great dust storms of recent decades have been made worse by periods of drought,

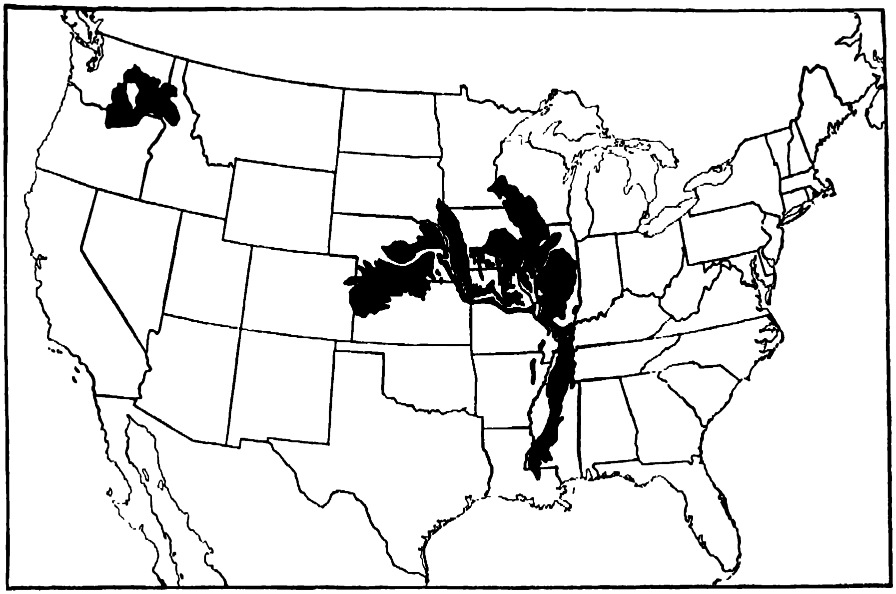


Fig. 235. The principal loess deposits of the United States. (*After C. F. Marbut, U.S. Dept. of Agriculture.*)

Fig. 236. An old roadway which has cut deeply into the loesslike material which mantles the bluffs and uplands east of the Mississippi floodplain near Natchez, Miss.

Fig. 237. The principal loess region of western Europe is closely associated with the margin of the older glacial drift (*cf.* Fig. 220). (*After Paul Woldstedt, Das Eiszeitalter.*)

and the material carried by them has accumulated locally in large quantities. Some dust is carried to great distances, however. Observation of some storms has shown that they distribute dust in appreciable quantity as far eastward as New England. In one storm the quantity deposited at Madison, Wis., was estimated at about 25 tons per square mile.[1] It is probable that there is at least a small admixture of loessial material in the surface regolith of most of eastern North America, southern Europe, and other parts of the world.

Europe. Associated with the region of older glaciation and glacial drainageways in Europe are considerable deposits of loess or loams of high loess content. They occur over a long belt which extends from central Germany eastward through southern Poland, beyond which it broadens into a vast area in central Russia and extends from Rumania to the steppe lands of the Caspian and Aral basins (Fig. 237). It is probable that there are also some areas of loess accumulation in the steppe lands of Siberia and Central Asia. These complete a discontinuous belt extending from northwestern Europe eastward across the entire Eurasian continent to include northern China.

North China. The large loessial component in the material of the delta plain of North China has been noted (417). Although this plain is composed largely of river sediment, much of it is of loessial origin. Either it is loess derived by stream erosion from the hill country to the west, or it was deposited by the wind on the delta surface and subsequently reworked by the shifting delta streams. Although such materials are not loess in the usual meaning of the word, true loess is believed to be a large component in the soils of all North China and as far beyond as the plains of Manchuria.

In the uplands of dry northwestern China the loess mantle lies thick on plains and slopes alike. The slopes are made tillable by terracing. In some areas mature gullying of the loess has produced "badlands," leaving little if any of the level uplands which may once have existed. Because of the tendency of loess to stand in steep slopes, this area shows certain cultural peculiarities. In some of the ancient roadways the loess has been crumbled by cart wheels and removed by wind and surface water for so many years that the roads now lie in steep-walled canyons many feet below the upland levels where they once were. Also in this region peasants have carved cavelike homes in the steep loess walls, and they till fields on the uplands which roof their homes.

Argentina. The Pampa of Argentina also is characterized by large areas of loess. In part they are aeolian loess, and in part they have been disturbed by streams, are interbedded between stream-deposited sands and clays of older alluvium, and are, therefore, like some of the deposits of North China, not true loess. In western Buenos Aires province the loess and loessial alluvium reach a total thickness of 50 to 100 ft. and in a few places as much as 500 ft.[1] These deposits are believed to have been removed by deflation from the arid belt near the Andes where extensive accumulations of rubble, gravel, and sand remain. The region of greatest loess accumulation has, like that of Nebraska, a subhumid climate.

[1] A. N. Winchell and E. R. Miller. The Great Dustfall of March 19, 1920. *Am. Journ. Sci.*, Vol. 3, pp. 349–364, 1922.

[1] R. Stappenbeck. "Geologie und Grundwasserkunde der Pampa." Pp. 382–409. Erwin Nägele, Stuttgart, 1926.

CHAPTER 18: *The Shore Features of Plains*

464. The Significance of Shore Features. The line at which the sea meets the land is a line of transformation. On its two sides are different scenes, different uses, and different means of communication. At that line the flow of trade from land to land by way of the sea must be handled for its ocean voyage. That process is in some places much aided, and in others distinctly handicapped, by the shape of the shore outline, the nature of the land features, and the depths of water associated with it. The harbor and freight-handling problems of a regular, or smooth, shore outline are different from those of one which has deep embayments or other features of a complex irregularity. The problems and profiles of shores which are flanked by mountainous highlands are different from those which open upon gently sloping plains. Because of the differences noted it will be found convenient to consider here, and at comparative length, the essential characteristics of the shores of lowland regions. Thus there will be reserved for later and briefer comment such modifications of the general features of coastal outline and profile as are found in association with plateaus, hill lands, and mountains.

465. Conditions Affecting Shore Outlines. The positions and shapes of shorelines are not unchangeable. On the contrary, several agents and processes work separately or together to bring about their constant reshaping and development. Among the more important of the conditions involved are the following; (*a*) changes in the relative elevation of land and sea, (*b*) changes resulting from wave erosion, (*c*) changes resulting from wave deposition, (*d*) changes resulting from land deposits, and (*e*) changes brought about through the work of corals and other organic agencies. Shoreline changes of the greatest extent would obviously result from any displacement of the land surface with respect to sea level. For example, if the land on a gently sloping plain, extending seaward as a broad, submerged continental shelf, were elevated only a few feet by diastrophic change or if there were a correspondingly slight lowering of the sea level by the withdrawal of water from the sea and its retention in great continental ice sheets, a large area of the shallow sea bottom would be exposed. The shoreline, under these circumstances, would migrate slowly seaward and occupy a new position on what had been the flat sea bottom. Such a shoreline would be characterized by regularity and few minor indentations. Landward from this shoreline there would be a plain of low relief having only such features as were made by wave erosion and deposition during the emergence and by the land-derived drainage that had to cross it (383). Seaward one would expect to find very shallow water resting upon a gently inclined sea bottom. Such a simple initial shoreline of emergence probably would not remain long unchanged. Waves and currents, by their gradational work, presently would add features that would complicate its outline, and minor diastrophic changes resulting in local submergence would do likewise. In fact, it may be doubted whether there are now in the world any extensive examples of the simple, straight shorelines of emergence bordered by flat plains which are uplifted sea bottom. Reasons for this are given below.

466. Shorelines of Submergence and Their Features. A general rise of sea level or a broad diastrophic depression of the lands would permit

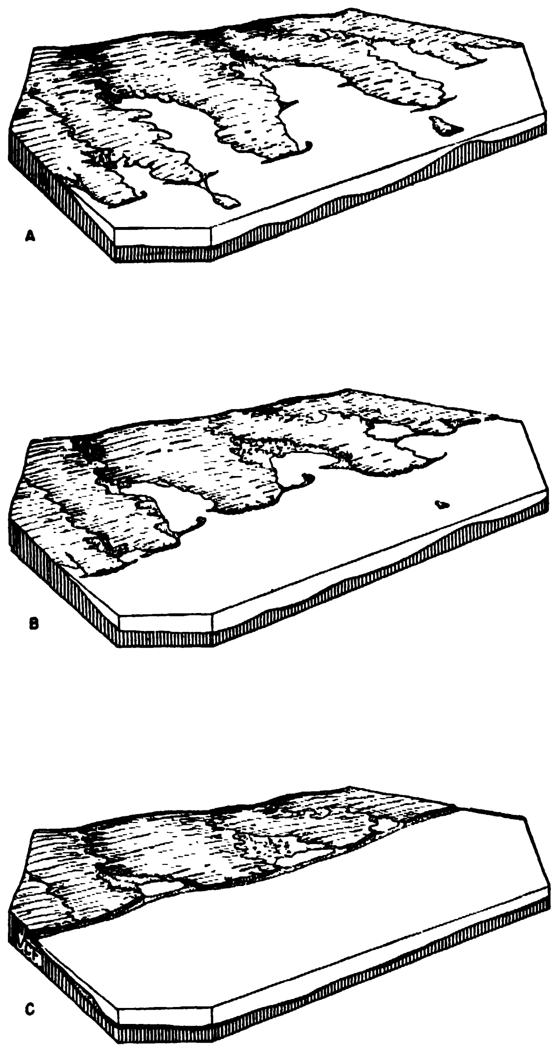


Fig. 238. Diagrams illustrating stages in the development of a shoreline of submergence. *A*, Erosion of the headlands has begun, and beaches, spits, and hooks are forming; *B*, depositional features extensive, shoreline retreating; *C*, shoreline worn well back and all features are approaching old-age stage.

landward encroachment of the sea and the establishment of new shorelines upon what was previously the land surface. Under these conditions the horizontal surface of the sea must intersect with the eroded surface of the land, and the new shoreline would assume a position which is that of a contour line upon the former land surface (Fig. 10). The measure of its irregularity would be determined by the slope of the land surface seaward and the degree of its previous erosional dissection.

The present widespread distribution of irregular shorelines bordering plains leads to the belief that some present conditions must be favorable to the submergence of coastal lowlands. These conditions apparently may be found in processes and events related to the existence and disappearance of the last of the great continental glaciers. While the glaciers existed, vast quantities of water were withdrawn from the oceans and locked on the land in the masses of ice. When the glaciers disappeared these waters were returned, raising the level of all the oceans by amounts variously estimated, but at least several score feet. Also it is believed that the land areas actually occupied by the continental glaciers were depressed or downwarped by the great weight of these glaciers. Although the ice largely disappeared several thousand years ago and the earth's crust in these areas is rising as a consequence of relief from that load, the rebound is exceedingly slow and is, as yet, incomplete. The lowlands of northeastern North America and northwestern Europe, therefore, still are at lower levels, perhaps both actually and relatively, than during the time just preceding the last glacial advance, and their margins are submerged.

The slow inundation of low coasts results first in the formation of shorelines of great irregularity. The relief features of an eroded plain, such as a coastal plain, usually are low but broad. Wide, shallow valleys are separated by broad, low interfluves (Fig. 161). Valleys of that kind have such low gradients that even a slight inundation permits the sea to enter them for some distance, causing bays. The interstream areas, at the same time, remain only partly submerged and appear as irregular peninsulas or as islands. Some such bays are highly irregular in outline. If the valleys were eroded in horizontal sedimentary or in massive rocks they normally are dendritic in pattern, and the bays that occupy them assume the branching forms of the valleys. Others are of simple outline, especially such as occupy glacially scoured troughs or depressions caused by faults trans-

verse to the shoreline. Individual embayments resulting from submergence are called "drowned valleys" or *estuaries*, and shorelines characterized by many of them are called *ria shorelines* (Fig. 238*A*).

467. Ria Shorelines. Examples of ria shorelines and estuarine rivers upon coastal lowlands are numerous. Much of the highly irregular shoreline of Great Britain and the lowland of northwestern Europe owe their configuration to the partial submergence of gently sloping plains. The same is true of a large part of the Atlantic and Gulf shores of North America. In the latter case, some of the individual estuaries, Chesapeake Bay, for example, are of the dendritic type (Fig. 239). Others, like Mobile Bay, Delaware Bay, and the lower Hudson and St. Lawrence Rivers, are relatively simple in outline.

The shorelines of northern New England and eastern Canada are of great irregularity, owing to the submergence of plains of ancient crystalline and sedimentary rocks of complicated structures and varying degrees of resistance to erosion. Some of the narrow bays are in part

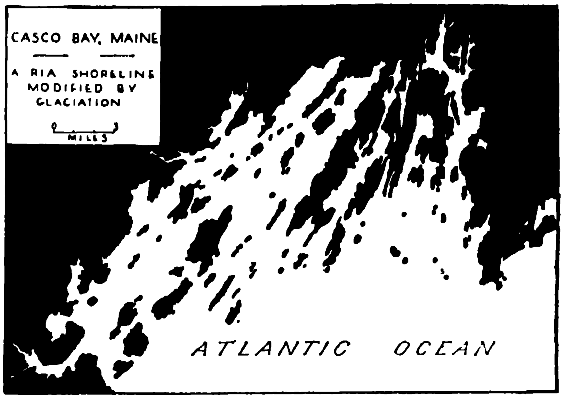


Fig. 240. The ria shoreline of Casco Bay has many islands, rocky peninsulas, and narrow inlets.

Fig. 239

the result of faulting in the rocks of the coastal zone. However, the present shorelines are not merely those of stream erosion and submergence but have also many details of outline and profile given them by ice scour during the period of their complete coverage by the continental glaciers. Although the features of submergence have been somewhat modified by wave and current action, some sections retain the high degree of irregularity of their youthful state. Such a shoreline is well illustrated by Casco Bay, Maine, which, according to W. D. Johnson, is a ria shoreline only slightly modified by glacial scour (Figs. 240 and 241).

46' The Utility of Ria Shorelines. In its youthful stage of development the ria shoreline has numerous estuaries together with certain deposited features, and it is one of great irregularity, with an abundance of sheltered water. Provided its bays are sufficiently deep, and many of them are, this kind of shoreline is one of numerous harbors and of great commercial possibilities. This is shown by the great use made of the Chesapeake, Delaware, New York, and other estuarine bays of eastern North America. The same is true of western Europe. The estuaries of the Rivers Mersey, Thames, Elbe, Weser, Seine, and Gironde have been capable of such great commercial use because submergence has deepened their waters, making possible the establishment of ocean ports at considerable distances inland from their mouths.

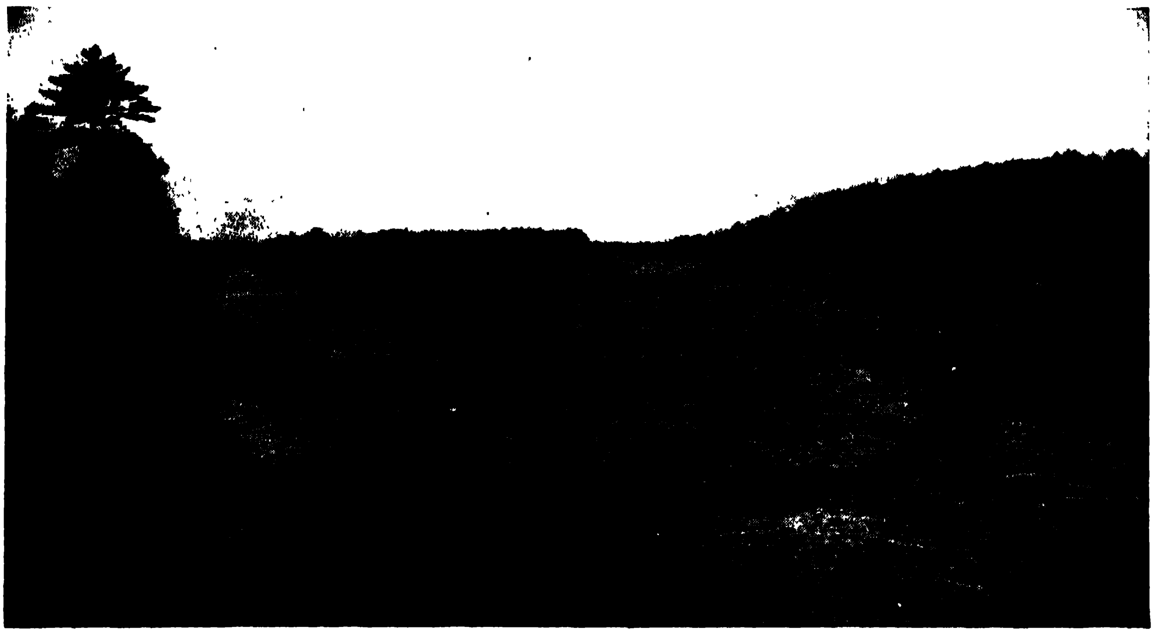


Fig. 241. A view to seaward from the landward end of one of the long arms of Casco Bay, Maine, at low tide.

The larger estuaries in the coastal plains of other continents serve in like manner, including that of the Rio de la Plata, which is the approach to Montevideo and Buenos Aires.

469. Shoreline Features Resulting from Marine Erosion. A newly established shoreline is subject to attack and modification by wave and current erosion. The attack is most effective upon those parts of the shoreline which are most exposed to the great waves of the open sea, especially the ends of projecting headlands. It is least effective in narrow or well-enclosed bays where waves of great size and force cannot reach. The effect of erosion upon the projections of exposed shorelines is to cut them back slowly and eventually to remove them, thus straightening the shoreline (Fig. 238*A*, *B*, *C*). On exposed coasts of easily eroded rock the rate of cutting is sufficiently rapid so that whole shorelines are known to be retreating landward at measurable rates. The shoreline of one part of England, for example, is known to have been cut back as much as 2 miles since the time of the Roman conquest. Shorelines of resistant rock retreat much more slowly.

During the erosional process certain characteristic shore features appear. Wave erosion is most effective near average sea level and cuts a notch in the shore profile there. This it enlarges by undercutting and, on strongly eroding shores, produces steep cliffs and bold headlands. The erosion of cliffs in unconsolidated material or weak rock is likely to proceed with comparative evenness, but, in resistant rocks, inequalities in rock hardness or the presence of numerous joints and other lines of weakness sometimes cause it to proceed unequally. Some of the results of differential erosion are the formation of eroded coves, detached chimneylike pinnacles of rock, and half-submerged projections upon the sea floor (Fig. 242).

As the sea cliff retreats landward under erosion, it leaves behind an eroded base which inclines gently seaward a little below sea level. It is called a *wave-cut terrace.* Some shorelines are bordered by marine terraces of that origin many hundreds or even several thousands of feet wide (Fig. 243). The shallowness of the water, especially on the newer landward margins of these features, and the presence of submerged rock projections cause them to be a menace to navigation.

470. Shoreline Features Resulting from Marine Deposition. *Onshore Features.* The rock debris provided by wave and current erosion, together with that derived from streams, is distributed in several characteristic orms along shorelines, and being added to the land, it greatly affects the shape and utility of the shore outline. On the more steeply sloping shores bordering sea cliffs, large quantities are moved offshore and are deposited beyond the margin of the wave-cut terrace in a form which may be called wave-built terrace. Material so deposited is of interest in its relation to the formation of sedimentary rocks, but it is deeply submerged and affects the shore outline but little. Of much greater present importance are the deposits that accumulate in the shallow shore waters and assume shapes and positions that greatly affect the appearance and use of the shoreline.

In the early stages of the erosional development of the shoreline of a coastal plain, sediment is carried by waves and currents into the protected waters of coves and bays, where it accumulates as *beaches* of sand or pebbles. Locally these fill irregular coves or bay heads, but their fronts are smoothly curved by wave and current action, and the deposits assume shapes that give rise to the name *crescent beaches.* As the headlands are cut back, the abundant

Fig. 242. The features of a wave-cut cliff on the exposed coast of Cornwall, England. (*Photograph by Burton Holmes. From Ewing Galloway.*)

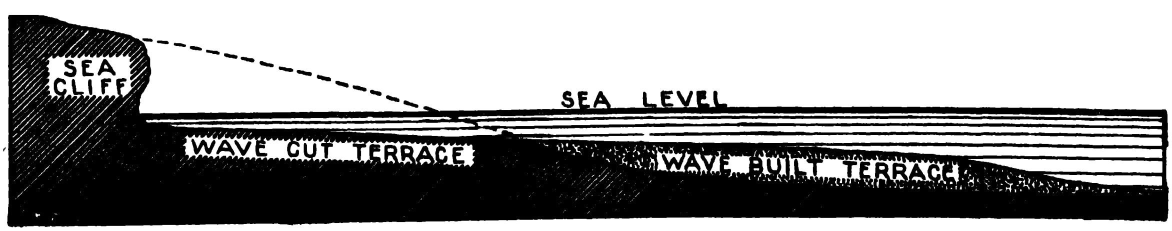


Fig. 243. A profile to show the association of features on an eroding shoreline.

debris accumulates in the shore waters and forms beaches even in front of the eroding shores. This material is subject to continuous removal and redeposition. With the aid of shore currents and undertow it is shifted alongshore until it comes to an angle in the shoreline or to the deeper water of a bay, where it is built up on the bottom in ridge form. These submerged ridges are added to until they grow above the water surface and project seaward or into the bays as points of sand or gravel which are called *spits*. In the mouth of a broad bay the shoreward movement of waves and currents past the projecting point of a spit may cause it to grow with a shoreward curve, when it is called a *recurved spit* or "hook." Such features are exemplified in the shapes of Sandy Hook, at the entrance of New York Bay, and the curved tip of Cape Cod. In a narrow or shallow bay a spit may grow entirely across the entrance, or a pair of them may grow, one from either side toward the middle, forming a *bay bar* (Fig. 238*C*). By deposits of similar nature adjacent islands may be connected with the shore.

Offshore Features. Shores having low relief and very shallow waters are characterized by wave-deposited features of another type. Along such shorelines the erosional work of the waves is weak because great waves begin to drag on the shallow bottom, change form, topple, and break at distances of hundreds or even thousands of feet out from the shoreline (385). In doing so they wash forward loose bottom material, only to drop it just landward of the line of breakers and build there a submarine ridge roughly parallel to the shoreline and at places touching it. As this feature grows in height it appears first above sea level as a series of spits and narrow islands (Fig. 244*A*). Further deposition by waves and the drift of longshore currents fills gaps between some of the portions and connects them. This forms a long low bar that is called an *offshore bar* (Fig. 244*B*). Between offshore bars and their mainland shorelines are long shallow lagoons. Drainage from the land discharges into the lagoon and seeks an outlet through the bar, and in the lagoon the water level rises and falls periodically with the tide, which flows in and out through gaps, or *tidal inlets*, between sections of the bar. This tends to keep some of the gaps scoured open.

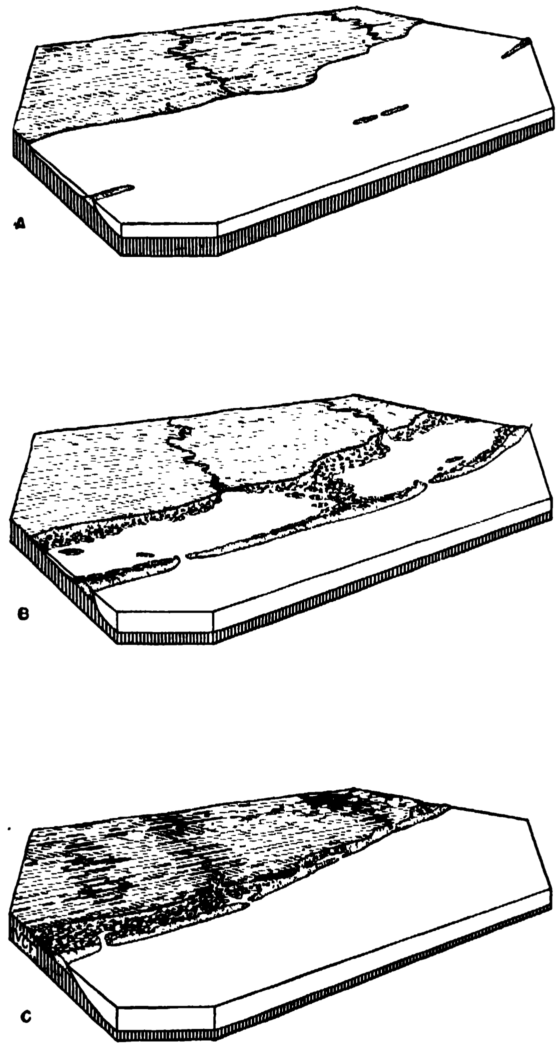


Fig. 244. Diagrams illustrating stages in the development of an offshore bar on a shore of low relief and shallow water. *A*, The beginning of a submarine ridge by wave deposition near the line of breakers; *B*, the growth of an offshore bar flanked by lagoons; *C*, under wave pounding the bar migrates shoreward and the lagoons narrow fill, or disappear.

An offshore bar does not extend indefinitely parallel to the mainland shore with complete separation from it by a lagoon. Rather it touches the mainland at intervals, especially at projecting points, thus interrupting the continuity of

the lagoon. For that reason the formation of a bar, broken by inlets, and of segmented lagoons tends to complicate a previously simple shoreline and greatly to lengthen it. It might appear that the many inlets, bays, and islands thus formed would afford protection to shipping and greatly increase the commercial utility of such a shoreline. To some extent they do so, especially for small craft. Canals dredged through the lagoons, connecting one with another, afford long protected routes for light coastwise traffic. It is to be noted, however, that, owing to the nature of the shore, storms are likely to produce very rough water outside the bar, and the approaches to the inlets are shallow, as are the lagoons and channels behind them. Many ships are grounded and lost on shores of this kind, and they are hardly less dangerous than rocky shores of marine erosion.

The formation of an offshore bar is followed by its slow migration landward and its eventual disappearance. Waves erode material from the bottom in front of the bar, thus deepening the water there, permitting them to attack and cut the front of the bar itself. This material is thrown up on the bar shore and is shaped into sand dunes or is wind-drifted back toward the lagoon, widening the bar at the rear as it is cut away in front. This process narrows the lagoon, and river sediment does its part also by aggrading that shallow body of water. After partial filling by sand and silt the lagoon acquires a fringing salt-water vegetation and, at low tide, may be only an expanse of featureless marshland. Eventually the shoreward migration of the bar carries it to the mainland, the lagoon disappears, and the bar becomes merely a beach upon a shore of simple outline (Fig. 244*C*). The time required for a transformation of the type described is long, but the shallow coastal waters of the world show numerous examples of offshore bars and lagoons in various stages of progress from youth to old age and extinction.

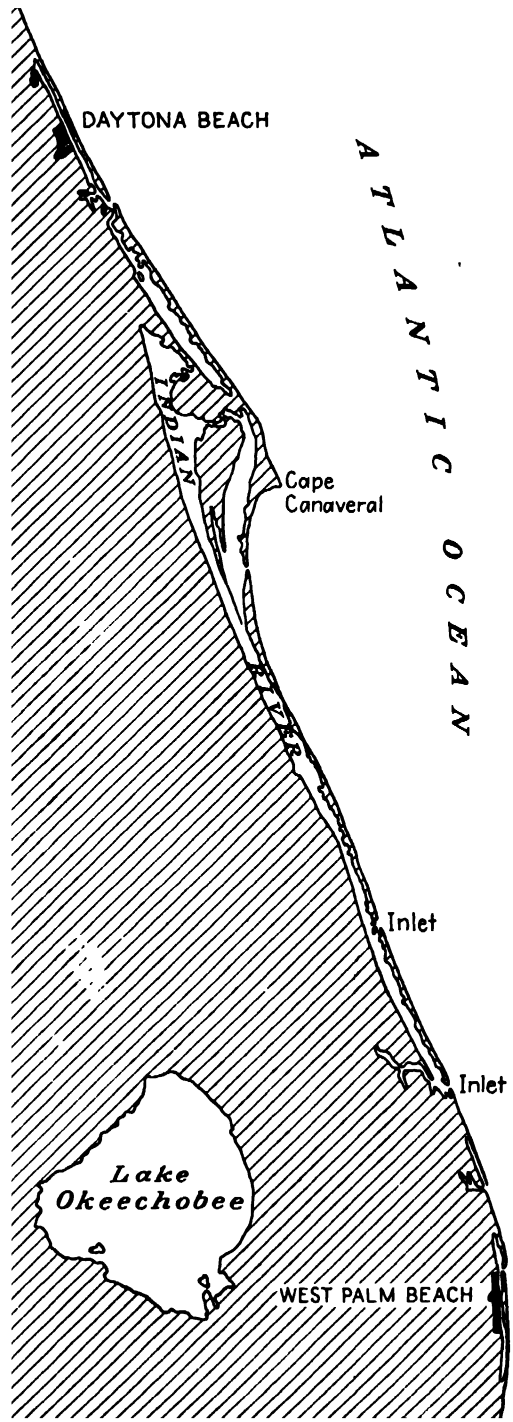


Fig. 245. The offshore bars and lagoons of the eastern coast of Florida.

471. Examples of Low Coasts and Their Shoreline Features. Among the numerous examples of low coasts with shallow water offshore, the Gulf and South Atlantic Coasts of the United States are outstanding. Except where

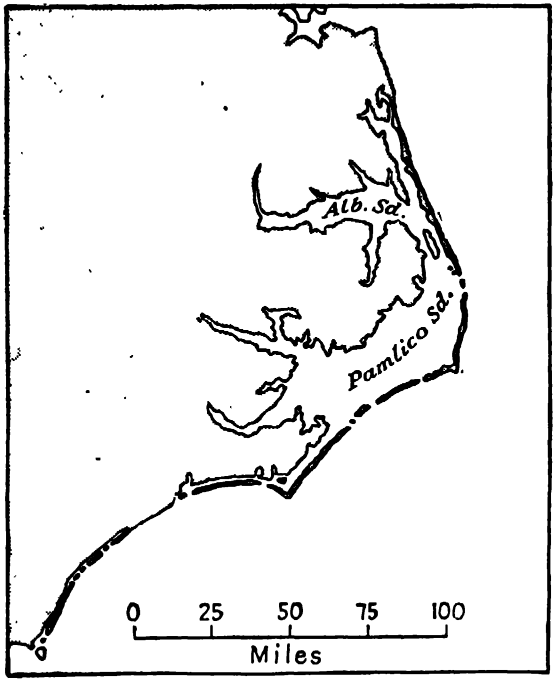


Fig. 246. Cuspate forelands or wave-modified offshore bars on the Carolina coast.

the Mississippi River Delta intervenes, they show generally the estuarine features resulting from submergence and numerous offshore bars which indicate shallow coastal waters. Padre and Matagorda Islands, on the Texas coast, are offshore bars, and behind them are extensive lagoons and broad shallow estuarine bays. Indian River, on the east coast of Florida, is a long narrow lagoon. Beyond it lies an offshore bar which extends coastwise for more than 100 miles, interrupted only by narrow tidal inlets. This association of bar and lagoon broadens northward into the complicated, current-built, dune-covered projection of Cape Canaveral (Fig. 245). The Carolina shoreline shows similar features (Fig. 246). The long bars developed there are made up of segments that meet at sharp angles. These appear to result from the influence of various shore currents. They enclose not only lagoons but such broad bodies of water as Pamlico, Albemarle, and Carrituck Sounds, which are in part estuarine. The bars on the New Jersey shore, on the other hand, are nearly straight, and they enclose only narrow lagoons. Similar features are found on many other lowland coasts. The North Sea Coast from Netherlands to Denmark is fringed by the long chain of the Frisian Islands, which are separated from the mainland by narrow lagoons. The large lakes on the coast of eastern Germany are cut off from the Baltic by long curving bars

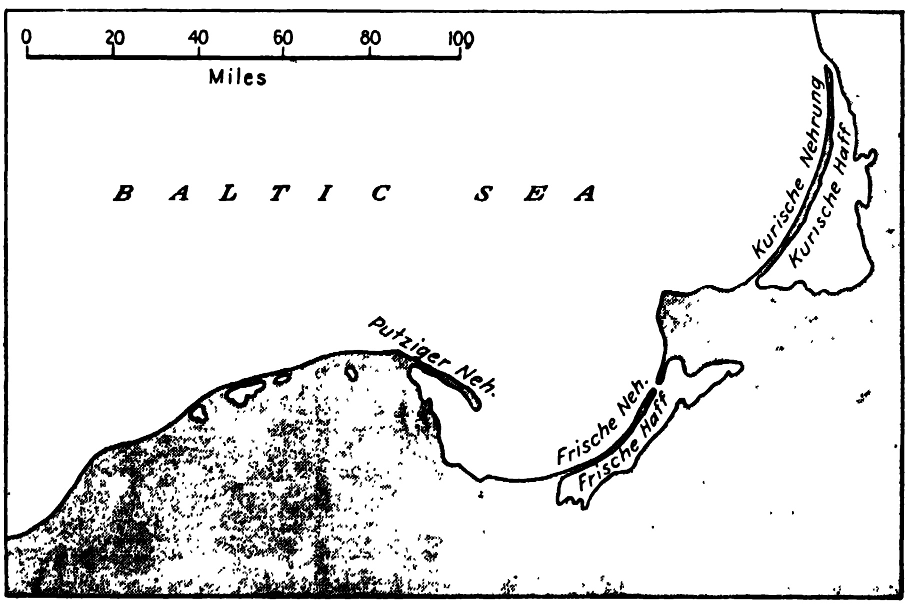


Fig. 247. The "Haffs" or lagoons and their enclosing "Nehrungs" or bars on the Baltic Coast of Germany. Each Haff has a narrow outlet to the sea.

coral rim.[1] A later partial submergence has drowned the river valleys, creating many commodious bays each having a narrow entrance. Cuba has many of these "bottleneck" harbors (Fig. 250).

Shorelines and Ocean Tides

474. Tides Affect the Features and Uses of Shorelines. The commercial utility of shorelines is much affected by the depth of their waters as well as by the shapes of their outlines. Shallow waters and regular shorelines do not favor commercial development, while estuaries and bays offer unusual facilities for that use. However, the appearance and use of most shorelines are somewhat modified by the occurrence of tides. By their periodic rise and fall, tides alternately deepen and shallow the shore waters, thereby causing difficulties in harbor construction and the movement of commerce. Tidal currents scour channels and keep open some that otherwise might quickly be choked with sediment, but they also create problems of navigation for those who use the channels.

475. The Nature of Tides. The tides are broad but very low bulges of the sea which result from the gravitational relation of the earth to the moon and the sun. Without the involved explanation of the cause of tides being attempted, the following facts regarding them

[1] T. W. Vaughan and A. C. Spencer. The Geography of Cuba. *Bull. Amer. Geog. Soc.*, Vol. 34, p. 116, 1902.

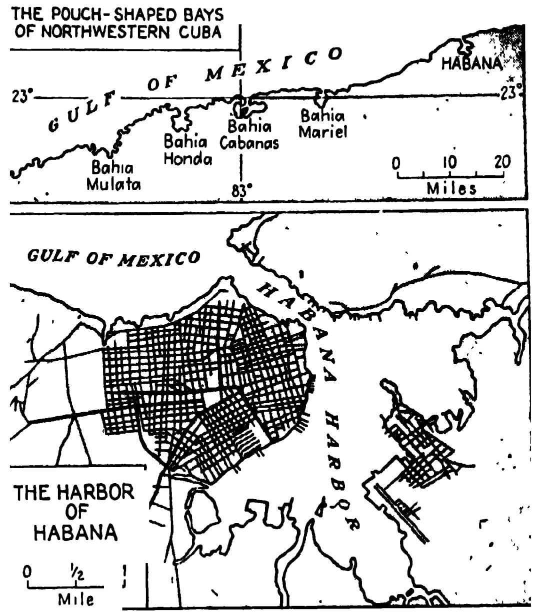


Fig. 250. (Above) A series of pouch-shaped or "bottleneck" bays on the northern coast of Cuba. (Below) Details of outline for that bay upon the shores of which the city of Habana is situated.

may be accepted: If there were no continents, and if deep oceans covered the entire earth, the moon and the sun each would cause two tidal bulges. The two caused by the moon always would be exactly on opposite sides of the earth from each other (Fig. 251). Their positions would be unchanging with respect to a line extending from the moon through the center of the earth, but they would advance westward

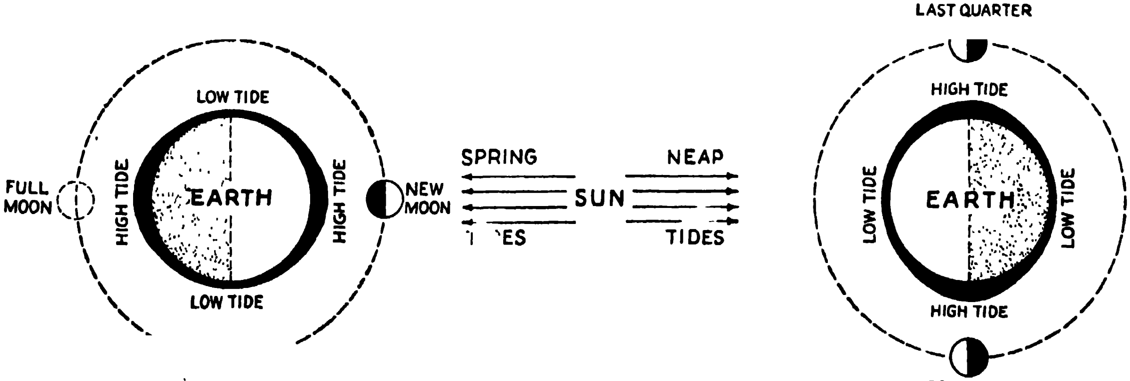


Fig. 251. A diagram to illustrate the relation of the moon in its different phases, and of the sun, to the occurrence of ocean tides.

across the oceans, because the earth rotates eastward. A given place on the earth would thus, during the time of one daily rotation, pass through each of the two lunar tidal bulges and each of the intervening lows. It should, therefore, have two periods of high tide and two of low tide during each 24 hr. However, the moon advances in its 28-day orbit about the earth at a rate that would delay the tidal recurrence somewhat, and the true period between successive high tides would, therefore, be approximately 12 hr., 25 min., rather than 12 hr.

The two tides caused by the sun also would be on opposite sides of the earth from each other and would have a relation to the sun like that of the lunar tides to the moon, but they are less than one-half as high as those caused by the moon. At times of new moon and of full moon the earth, moon, and sun are nearly in line, the lunar tides and the solar tides occur in the same places, and the height of the solar tides is added to that of those caused by the moon. This causes the high tides of those periods to be unusually high and the intervening low tides of the same periods to be unusually low. They are the periods of *spring tide*, which recur every two weeks. When the moon is at its first and third quarters the earth-sun line is nearly at right angles with the earth-moon line. The solar tides then fall between, and detract from, the lunar tides. That causes the difference between low and high tide at that time to be less pronounced than usual. They are the periods of *neap tide*, which also recur every two weeks.

476. The Occurrence of Tides. Although, under ideal conditions, equal high tides should

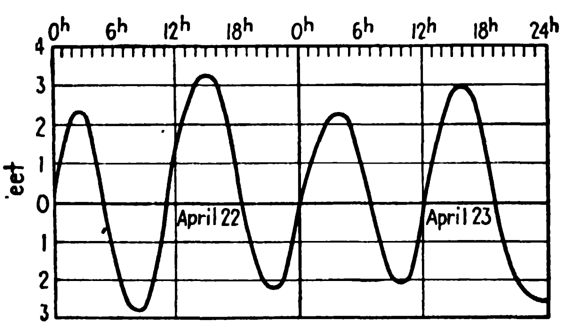


Fig. 252. The intervals and amounts of tidal rise and fall at New York during a 48-hr. period. (*After H. A. Marmer.*)

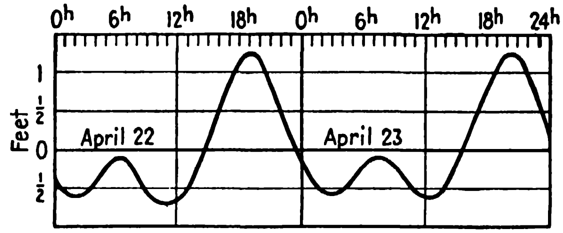


Fig. 253. The intervals and amounts of rise and fall of a tide of mixed type at Honolulu. The period is the same as that in Fig. 252. (*After H. A. Marmer.*)

succeed each other at intervals of 12 hr., 25 min., that is not the actual condition in many places. Owing to the trends and outlines of different coasts, the depth of coastal waters, the shapes and sizes of the several oceans, and other causes, there is a considerable variation in the height of successive tides at any given station and in the intervals between them. In general, the tides of the Atlantic Ocean conform most nearly to the ideal type. This may be illustrated by a curve showing the actual rise and fall of the tide at New York (Fig. 252). On some shores, notably parts of southern Asia and the Caribbean and Gulf shores of America, there is but one high tide per day.[1] The shores of the Pacific Ocean generally are characterized by what may be called mixed tides. In them each alternate high tide is much lower than the preceding one. This condition may be illustrated by a curve showing the actual tidal rise and fall at Honolulu (Fig. 253).

477. Tidal Range. Not only do the tides of various places differ considerably as to time of their rise and fall, but they differ even more greatly as to amount of rise and fall. The average difference in water level between low and high tide at any place is called its *tidal range*. In the open ocean it is so slight as not to be noticeable. As the tidal bulges, or waves, approach coasts, however, they tend, like other waves, to increase in height. The amount of the increase is determined by a number of factors. The tides of nearly enclosed bodies of water, such as the Mediterranean and Baltic Seas, are so slight as to be

[1] H. A. Bauer. A World Map of the Tides. *Geog. Rev.*, Vol. 23, pp. 259–270, 1933.

negligible. In sheltered waters, such as the Gulf of Mexico and the Caribbean Sea, the range is small, usually less than 2 ft. Common tidal ranges on exposed coasts are between 5 and 10 ft., though in some places less and in others more. In a few localities, some of them the sites of important commercial ports, the tidal range is so great that it is a distinct handicap to the use of the shore. Some harbors, notably Liverpool, England, have required expensive improvements to offset the disadvantages of the continuous rise and fall of the water level while ships are loading and unloading cargo at the wharves. Places of great tidal range mainly are situated upon funnel-shaped bays or estuaries, where the range increases with distance from the bay mouth toward its head. Cherbourg, France, has an average tidal range of 17 ft., and Liverpool has a range of 29 ft. The head of the Bay of Fundy, Nova Scotia, has 42 ft. and, at time of spring tide, sometimes as much as 50 ft. of extreme tidal range. Even in the rivers and harbors tributary to the Bay of Fundy ships are temporarily stranded at low tide only to be afloat again a few hours later when the tide sets landward.

CHAPTER 19: *Plateaus*

478. The Distinguishing Features of Plateaus. Plateaus may not always be distinguished easily from the other major physiographic subdivisions of the land. In general, they are characterized by broad uplands of considerable elevation above sea level. Some parts of plateau surfaces are likely to be traversed by deeply cut and relatively narrow stream valleys which give them, as a class, a high degree of relief. But the deep narrow valleys characteristically are so widely spaced that only a small part of the entire plateau surface is dissected into steep slopes. The ideal plateau is, therefore, high and deeply trenched by narrow valleys, and its interstream areas are broad and flat topped. It is the perfect example of the youthful stage in the cycle of erosion.

However, few plateaus are ideal in form. High and much dissected plateaus, on the one hand, grade into hill lands and mountains, while low and little-dissected plateaus, on the other, grade into plains. The only features by which plateaus may conveniently be distinguished from plains are their relative degree of local relief and their abrupt termination. *Tabular uplands having a relief of more than* 500 *ft. may be arbitrarily defined as plateaus.* In addition, some plateaus are situated so that they terminate in escarpments which make them appear high from at least one side. Most of the great plateaus of the earth have an average elevation of at least 2,000 ft. above sea level. That, however, is not particularly distinctive, since some plains are higher. The High Plains of the United States reach an altitude of more than 5,000 ft. but usually are thought of as plains, because, except in their southern portion, they join the interior plain of the continent without the interruption of any high escarpment and because of their relatively low degree of local relief.

479. Plateaus Classed According to Their Physiographic Relationships. The great plateaus of the earth, shown in Plate V, are of three major types, when classed according to their physiographic relationships: (*a*) intermontane plateaus, (*b*) piedmont plateaus, and (*c*) continental plateaus, or tablelands.

480. *Intermontane plateaus* are segments of the earth's crust uplifted in association with mountains and more or less nearly surrounded by them. The highest and some of the most extensive plateaus are intermontane in situation. The plateau of Tibet is an eastward-sloping highland much of the surface of which lies at elevations between 10,000 and 15,000 ft. above sea level. On the south of it rise the great heights of the Himalayas, and on the north are those of the Altyn Tagh and the Kunlun. Eastward and westward are mountain borders also, and surplus drainage escapes from the high-rimmed plateau only through deeply cut valleys and gorges which notch the mountain margins. The Altiplano, or high plateau of the Andes, lies between eastern and western ranges of the mountains, also at elevations between 10,000 and 15,000 ft. These are the highest of the great intermontane plateaus, but others of similar situation are found at lower elevations. Among them are the dry plateaus of Mongolia and the Tarim Basin, in Asia; the plateau of Mexico; and, in the United States, a large part of the Great Basin and the Columbia Plateau.

481. *Piedmont plateaus* lie between mountains and bordering plains or the seas. Of small piedmont plateaus there are many, but large ones are few. One illustration is found in the plateau

section of the intermontane plateaus of western United States (346).

In American dry lands, a plateau upland of small to moderate size and tabular form (flat top and steep sides) is called a *mesa* (Figs. 257 and 258). Usually mesas are portions of larger plateaus from which they have been detached by the formation and widening of arroyos, or canyons. In fact the normal progress of erosional development in dry plateaus, through canyon formation and lateral cutting, tends to separate and ultimately to isolate such features and they become outliers. As the valleys are widened the marginal plateau blocks are reduced in area through erosional attack on all sides, but they retain their flat tops. Features of the same origin but of smaller size often are called *buttes* (Fig. 258). In some dry plateaus of poorly consolidated sediments erosion has almost completely destroyed the flat upland. Only small mesas, buttes, and pinnacled divides remain, separated by fantastically carved arroyos. Surfaces of that kind merge without distinction into low mountains, on the one hand, or, on the other, into hill country of the badland type (500).

491. Plateau Bolson Lands. Some dry plateaus, like some dry plains, are comprised of *bolsons* or regions of interior drainage (454). Because the streams of plateau bolsons drain toward their lowest interior points and not into the oceans, each bolson has its own local or temporary baselevel of erosion and cannot be deeply dissected. Thus their surfaces have many of the same general features as those of basins in dry plains, from which they may be distinguished mainly by their greater actual elevations above sea level and by the fact that some of them are intermontane in situation. In them are to be found the same rocky pediments, the same alluvial fans, the same desert pavements, and similar collections of drifting sand. At their lowest points, likewise, are features that give evidence of collecting drainage. Some of them contain notable salt lakes. Such are Sevier Lake and Great Salt Lake, Utah; Mono Lake, California; Tengri Nor, Koko Nor, and others, in the plateaus of Central Asia; the lakes of Persia; and Lake Poopó, Bolivia. Not all lakes of dry-plateau basins are salt. Some of those at higher elevations overflow into lower basins and are kept fresh thereby. That is true of Lake Titicaca, Bolivia, which overflows into Lake Poopó, and of Utah Lake, which overflows into Great Salt Lake.

There is abundant evidence to show that some of the present salt lakes are only the dwindled remnants of once greater lakes, some of them fresh-water lakes. Great Salt Lake, for example, was so much larger and higher during glacial times that it overflowed the rim of its basin and discharged northward into the Snake River and so to the Pacific Ocean via the Columbia. It was then a great fresh-water lake. When the water supply from shrinking mountain glaciers decreased, the level of the lake began to lower, owing to the excess of evaporation over inflow. Presently it had no outlet, and its salt content began to increase. Abandoned shore terraces and broad salt flats now mark various levels at which the dwindling lake stood at certain stages during the long process of reduction to its present small size and salt saturation. Many plateau basins have not enough water to maintain permanent lakes but contain salt marshes. Examples are seen in the "pans" of South Africa, the Tsaidam Swamp of Central Asia, the Salar de Uyuni of Bolivia, and the Humboldt Salt Marsh of Nevada.

Plateau Features Developed in Humid Climates

492. General Features. Plateaus that are situated in regions of humid climate tend to be more minutely dissected by stream erosion than are those in regions of dry climate. Some, indeed, are so dissected that they have lost most of their plateau characteristics. The degree of dissection differs, however, not only with the amount and distribution of precipitation but also with the altitude of the plateau, the gradient of its streams, and the kind and structure of its rocks. The Eastern Highland of Australia, the eastern front of the Brazilian Plateau, and the western front of the Deccan Plateau of India

receive heavy rainfalls, are near the sea, and have gradients so steep that they have been dissected into hill regions, locally called mountains. In Brazil and India the precipitation on the broad plateau uplands, though fairly abundant, is less than on the fronts. The drainage from them takes longer routes to sea level and erodes less deeply. Also, in some cases at least, dissection is further retarded by the establishment of temporary baselevels upon the surfaces of resistant rim-rock formations, as, for example, in the rainy Congo Basin of Africa. Although the dissection of that plateau is in progress the basin still is in the youthful stage of erosion, and its surface is relatively flat.

493. The minor features of humid-land plateaus differ from those of arid plateaus largely because of vigorous downward stream erosion and the greater rapidity of the weathering processes, soil creep, slumping, and other phases of mass wasting. Some of the stream valleys are canyonlike, but generally they have walls that are less steep and less continuous than are those of the dry plateaus, since they are more frequently notched by the valleys of the more abundant tributary streams. Broad divides with rounded and irregular upland surfaces are common. In plateaus of slight dissection the upland features do not differ greatly from those of plains under similar climatic conditions. In those of deep dissection the uplands take on tabular form but usually with more rounded features than those of arid lands. This is particularly true in areas of igneous and metamorphic rocks. Resistant sedimentary formations sometimes retain angular escarpments, but usually the rapidity of weathering is sufficient to mantle their lower slopes with piles of talus. In the humid plateaus of the tropics remarkably deep accumulations of regolith blanket both upland levels and lower slopes, and cliffs of bare rock are exposed mainly on upper slopes, where they have been bared by soil creep. Indeed, it is probable that the rounded forms common to uplands in the humid tropics are due more to the slow creep and flow of the deeply weathered regolith than to its removal by surface erosion. Plateau landforms of the dissected type here indicated are illustrated by the broad uplands and deep gorges of limited areas in the Allegheny-Cumberland highland, the highlands of southwestern China, and the Ardennes highland of western Europe. Parts of these uplands are so greatly dissected that they approach hill regions in appearance and merge with them in features. Similar features are common also in the plateaus of eastern Brazil, Central America, and equatorial Africa.

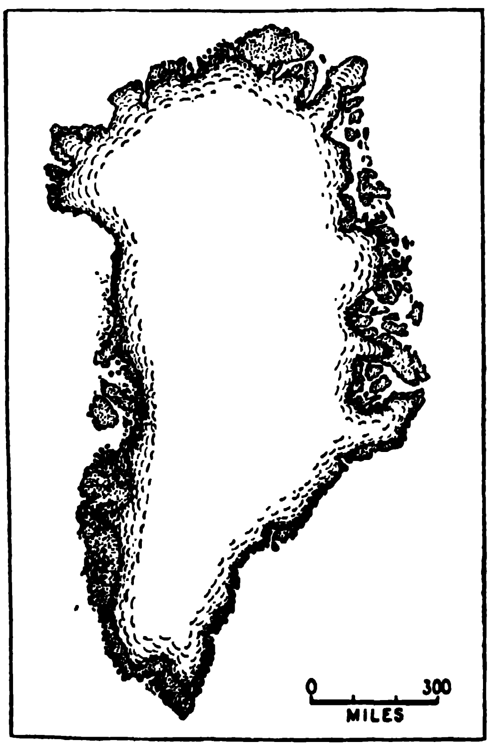


Fig. 259. The continental glacier of Greenland.

The Great Ice Plateaus

494. Surface Features. Vast sheets of ice cover most of Greenland and the Antarctic continent. Presumably they are so nearly like the great ice sheets which once covered large parts of North America and Europe that they may be considered examples for the study of the conformation and behavior of the former continental glaciers (375). Both of the existing glaciers may be regarded as great desert plateaus. The Greenland plateau is to a degree intermontane, since its ice is largely held within

Fig. 260. Tongues from the Greenland Ice Plateau protrude coastward through the fringing mountains and create nunataks by the isolation of rocky peaks. (*Photograph by Rasmussen. Courtesy of the Geographical Review, published by the American Geographical Society of New York.*)

fringing mountain walls. That of Antarctica for the most part rises sheer for several scores of feet and then slopes rapidly up to a flattish interior which has an average elevation of about 6,000 ft. and a maximum of about 10,000 ft. in the region inland from the Pacific Coast. Its vast expanse includes an area about one and two-thirds times the size of the United States, almost entirely ice covered. The relief features of the underlying Antarctic continent are little known, but its average elevation is believed to be considerable. It may be that the ice sheet over the interior does not in many places exceed 2,000 ft. in thickness and that in some places it is very thin.[1]

The surfaces of the great ice plateaus are notably different in features from those of other plateaus. In general they are flat. On their surfaces are parallel ridges a few feet in height which result principally from the work of the wind and drifting snow. But, owing to the cold, there are no streams, and consequently there are no features comparable with the mesas and canyons of the arid plateaus or with the rounded blocks of those in humid climates. If features of such great size could be formed, the slow movement of the plastic ice would presently close the valleys, engulf the eminences, and reduce the surface to its present monotony of uniformity.

495. Marginal Features. Only upon their margins do the great ice plateaus exhibit any variety in surface features. In this respect the plateaus of Antarctica and Greenland differ considerably. The ice surface of Antarctica descends from the high interior, and the marginal ice thins and is traversed by deep cracks. Except in a few localities, where it is held back by fringing mountains, the ice everywhere overruns the land margin so that the exact position of the shoreline of the continent is not known. The ice edge, whether it is at the land margin or well out into the adjacent sea, is marked by sheer cliffs. From these walls great icebergs are split off along crevasses as a result of undercutting by waves and the buoyant effect of the sea water. Some of them are tens of square miles in

[1] R. F. Flint. "Glacial Geology and the Pleistocene Epoch." John Wiley & Sons, Inc., New York, 1947.

area, tabular in form, and almost mesalike in their relation to the parent mass. The icebergs, large and small, disintegrate by melting and disperse as masses of floe or drift ice which fringe the continent for many miles and combine with the ice wall to make it relatively unapproachable.

The highland or mountainous rim of Greenland, and the higher summer temperatures prevailing there, produce somewhat different features upon the margin of that ice plateau. Not everywhere does it descend to the sea (Fig. 259). Since it is held back by the highlands, much of its southern and western front wastes by melting some distance inland. Where it does discharge into the sea it does so by means of tongues of ice, some narrow, some wide, which protrude through gaps in the bordering highland. Between parts of the ice tongues and surrounded by them are islands of rock, called *nunataks,* which are the peaks of ice-enveloped hills or mountains. These become more numerous near the plateau margin where the hills are higher and the ice thinner (Fig. 260). There are nunataks in Antarctica also, but they are considerably less numerous. From the tongues of Greenland ice which discharge directly into the sea are derived irregular icebergs which, although they are not so large as some seen in Antarctica, are of ample size to create a hazard to navigation when they drift southward into the foggy North Atlantic steamship lanes in the spring (Fig. 288).

CHAPTER 20: *Hill Lands*

496. Hill Lands Distinguished. The word hill has the misfortune to be applied in common use to elevations as greatly different as mounds and mountains. However, it is desirable that hills be set apart for consideration because there are some ways in which both their appearance as elements of landscape and their degrees of human utility differ from those of plains, plateaus, and mountains.

Hill lands are different from plains, even rough plains, in that they have, by definition, considerably greater relief. They differ from plateaus in that they are more minutely dissected and have smaller upland areas. They resemble mountain regions in that they include land of which a large part is in steep slopes. Some very rough hills are mountainlike in comparison with adjacent plains and locally are called mountains. However, in most hill regions the features are less massive than those of mountains, their parts are less complicated, and their detailed features are of a smaller order of size. Although the lines of distinction must be drawn arbitrarily, it will be useful to think of hill lands as being those parts of the earth's surface which (*a*) are so dissected that much of the land is in considerable degrees of slope, (*b*) have uplands of small summit area, and (*c*) have local relief of more than 500 but less than about 2,000 ft.

The principal world regions of hills, shown in Plate V, differ considerably, both between regions and between parts of the same region. They differ in their relations to other classes of physical features, in their climatic situations, in their geologic structures, and in their details of relief. It will be observed from Plate V that some of them border plateaus, of which they are the dissected margins. Others fringe mountain masses; still others stand alone in the midst of plains. Few, if any, hill regions derive their features directly from faulting, folding, or volcanic activity. Instead, they acquire them as a result of climatically controlled weathering and erosion in highlands of various origins and structures. Consequently, there are some hill regions that have developed under similar climates but in different kinds of rock, others that have developed in similar rock structures but under great differences of climate. Given similar conditions of structure and climate, there arise also differences in relief features which are due to local inequalities in the stage of maturity to which the erosional cycle has progressed. There are, for example, hill regions that have evolved through the submature dissection of plateaus. These may retain considerable parts of the old plateau surface in the form of broadly rounded hills which are separated by narrow and steep-sided valleys. However, hill lands of ideally mature dissection are reduced almost entirely to a succession of hills, narrow ridges, and V-shaped valleys in which level land may occupy less than 5 per cent of the total area. Some hill regions have been so long subjected to erosion that they are past the extreme irregularity of maturity. Such a region may retain only remnants of its former highland in the form of subdued hills of small summit area, among which open rolling valleys and basins are interspersed.

It is obvious that the advantages of hill lands for human settlement and use are intermediate between those of plains and mountains. Maturely dissected hills, having many steep slopes, are badly adapted to tillage. Although those in early maturity of erosion may include some

fairly level, plateaulike uplands, these are likely to be separated from each other and from outside regions by steep-sided valleys. Hill regions in a more advanced erosional stage, however, have broadly open valleys and reduced slopes and offer greater advantages for agriculture. Resources of other types are not lacking in hill regions. Because their slopes are in part steep and untillable, some have retained their forests, and they give rise to streams having steep gradients capable of development for water-power production. Rough lands, forests, and swift streams tend also to give them scenic attractiveness and to encourage their development as resort centers. Some also, by the nature of their geologic origin, contain mineral resources of value and have attracted mining industries and settlements.

In the following paragraphs a few of the more common kinds of hill lands may be considered with respect to some of their characteristic features and patterns of arrangement.

Stream-eroded Hill Regions

497. Hills in Regions of Horizontal Strata. Some of the roughest hill lands of the world have resulted from mature stream dissection of nearly

Fig. 261. An aerial view of the Allegheny hill region of West Virginia shows it to be a stream-dissected upland with a dendritic valley pattern (*cf.* Fig. 152*B*). (*Photograph by John L. Rich. Courtesy of the Geographical Review, published by the American Geographical Society of New York.*)

499. Other Hill Regions of Horizontal Strata. The Allegheny-Cumberland hill region is undoubtedly the largest region in the world of the class of landform above described, but there are many others of some size and importance. Among them are the Ozark hill lands and the Boston "Mountains" of Missouri and Arkansas, the hills bordering the Drakensberg Mountains in southeastern Africa, and parts of southern Germany.

500. Badlands. It has been noted previously that mature dissection of plains of poorly consolidated sediments produces very rough surfaces (399). Some of that nature have a high degree of local relief and, under subhumid climate, have been eroded into astonishingly complicated hill forms and patterns. These are not essentially different in stage of development from the Allegheny region but differ considerably from it in steepness and in fineness of erosional detail and in having lower relief. It was the bewildering maze of sharp hills and dry ravines that led the French fur traders to call those of the Great Plains, near the Black Hills, *mauvaises terres pour traverser*. They are eroded in thick beds of clay and in large part are but deeply and minutely dissected plains (Fig. 264). Still other badlands are found in certain easily eroded rock formations in the dry southwestern plateaus and mountain borders. However, extremely rapid dissection in almost any uniform material will produce similar features. Badland forms eroded in crystalline metamorphic rock of uniform texture are known in the treeless highlands of dry northern China.

501. Hills in Regions of Folded Sedimentary Strata. Certain hill regions are characterized by ridges and valleys of linear and roughly parallel patterns of arrangement. These contrast sharply with hills having the dendritic valley pattern discussed above. The linear pattern results from the erosion of elongated folds or crustal wrinkles made by lateral compression in sedimentary rocks of unequal resistance to erosion. Among the notable areas of that kind of surface configuration are the Appalachian ridge-and-valley region which extends from northeastern Pennsylvania southward to Ala-

Fig. 264. The features of badlands in western North Dakota. (*U.S. Geological Survey photograph.*)

Fig. 265. A view across the parallel ridges and valleys of one section of the folded Appalachians. Water gaps cut two of the ridges at the extreme right. In many parts of the ridge-and-valley region the valleys are much wider than those shown here and contain large areas of farm land (see Fig. 268). (*Photograph by Fairchild Aerial Surveys, Inc.*)

bama, the Ouachita Mountains of Arkansas, and the Jura Mountains on the French-Swiss border.

502. *The Jura Mountains* illustrate the parallel arrangement of hills in their least complicated form of development. In them ridges, most of which are not more than 500 to 2,000 ft. in height above the adjacent valleys, trend for many miles in a northeast-southwest direction, roughly parallel with one another. They are high cuestaform ridges, the eroded bases of resistant members of anticlinal and synclinal folds and parallel fault scarps. The intervening valleys, eroded in the less resistant sediments, are fairly broad. Although they do not include much high-class agricultural land, they contain most of the farms, roads, and villages of the region. Access from one valley to another is through notchlike gorges, locally called *cluses*, which have been cut across the linear hills by the major streams as they eroded downward in developing the present relief.

503. *The Appalachian ridge-and-valley region* is the most notable example in the world of parallel ridges and valleys (Fig. 265). It differs from the Jura region in that it is in a second cycle of erosion. During its first cycle rugged mountains, the product of intense folding and faulting, were reduced to a peneplain. The region has since been somewhat reelevated, the principal streams have cut into the plain along the courses in which they previously flowed, and their tributaries have adjusted themselves to the structural conditions by etching out new valleys in the less resistant strata. There are several important results of the progress of this second cycle of erosion. (*a*) Broad, rough-floored valleys have been carved in the less resistant rocks, mainly limestones and shales. (*b*) The upturned edges of the resistant members of the folds, usually sandstones and conglomerates, are left standing in relief in the form of long, even-crested ridges the summits of which represent the surface level of the old peneplain (Fig. 266). The major ridges range in height from 500 to 1,500 ft. above the adjacent valleys. They seldom are more than 3 miles wide, but some of them extend almost unbroken, and of remarkably uniform height, to lengths of 25 to 100 miles or more. (*c*) Narrow notches, called *water gaps*,

have been cut through the ridges where the major streams run across their trend. Other notches, begun by streams that changed their courses and abandoned the notches, are called wind gaps. These gaps are the gateways between adjacent valleys. (*d*) The streams in accomplishing this erosion have adjusted their courses to the trend of the rock structure with the result that a somewhat rectangular pattern of drainage, called *trellis drainage*, has evolved (Fig. 267).

Some of the valleys of this region are noted for their great continuity, and a few for their agricultural productivity. The most famed is the "Great Valley," which, under several local names, extends from New York to Alabama. The ridges, because of their steep slopes and thin infertile soils, remain principally in woodlands. A general view "across the grain" of the region includes wooded ridge beyond wooded ridge, with intervening valleys upon whose undulating to rolling bottoms are the fields and patchy woodlands of farms, together with highways and villages (Fig. 268).

Enclosed Valleys. Not all the ridges of the Appalachian ridge-and-valley region are parallel. The anticlines and synclines of which they

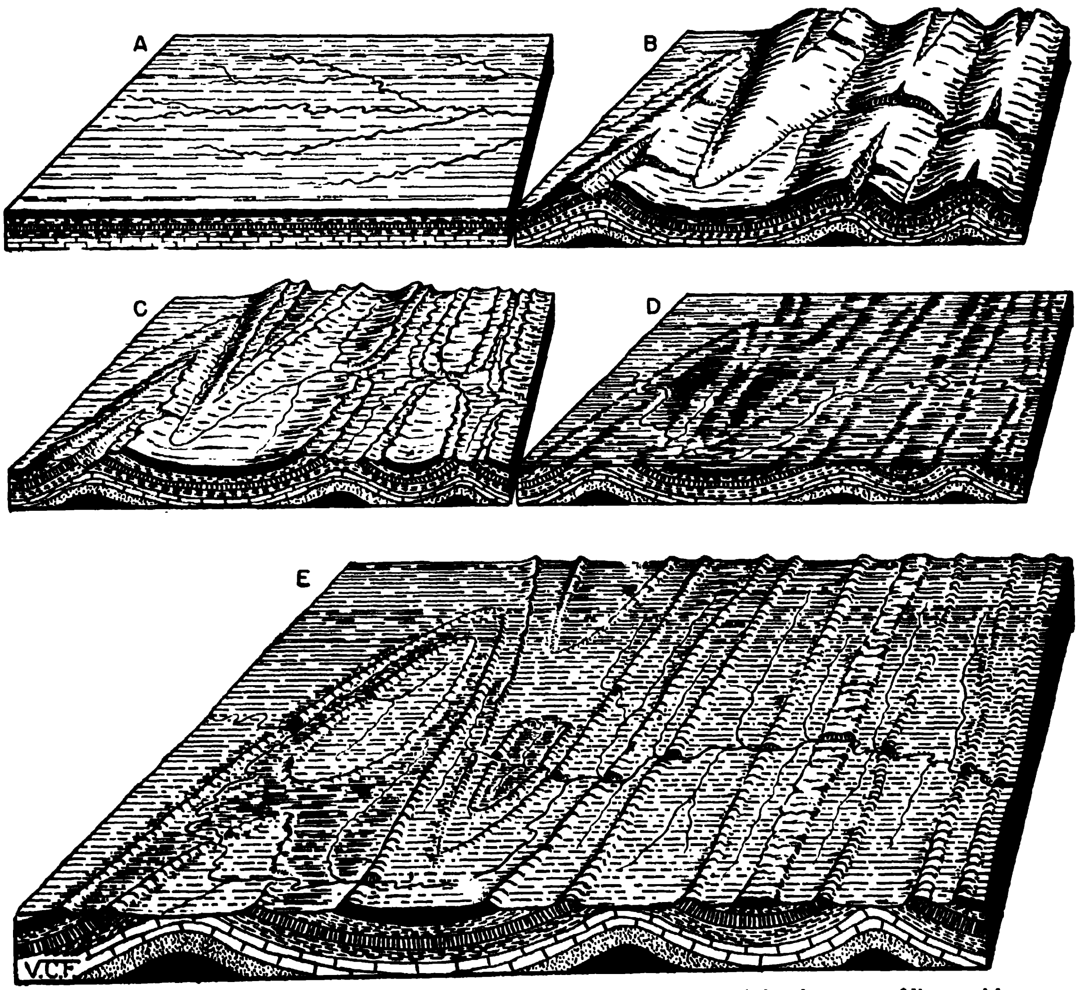


Fig. 266. A series of diagrams in chronological sequence to illustrate the erosional development of linear ridges, parallel valleys, and enclosed valleys. *A*, horizontal strata; *B*, anticlinal and synclinal folding, with pitching anticlines; *C*, erosional mountains cut in the folded structures; *D*, the region eroded to baselevel; *E*, the peneplain slightly elevated and re-eroded. Linear ridges, broad valleys, enclosed or canoe-shaped valleys, and water gaps are shown. They are of types seen in the folded Appalachians.

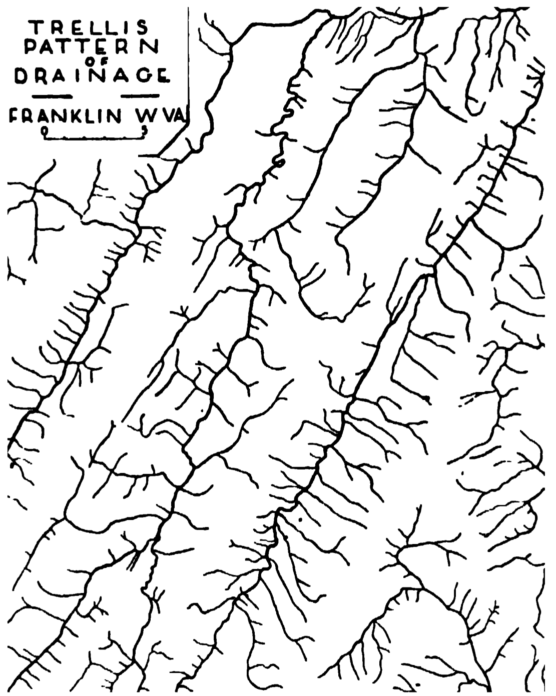


Fig. 267. The type of drainage pattern developed in association with relief features and rock structures like those shown in Figs. 265 and 266.

are the eroded stumps sometimes terminate abruptly, pitch gently beneath the valley level, or merge with one another. Such structures are the causes of great variation in the shapes, sizes, and continuity of the valleys and, consequently, in the patterns of settlement and the routes of transportation that follow them. Figure 266 shows two enclosed, canoe-shaped valleys which result from the erosion of anticlinal structures. Such a valley may be underlain by limestone and contain productive agricultural land, but it is isolated, since the narrow water gap of the stream that eroded it is the only low-level gateway to it.

504. Hills in Regions of Complex Rock Structures. Among the hill regions of the earth it is probable that the greater number are comprised of intermingled rocks of many different origins and highly complicated structures. Some of the regions are, in fact, the eroded remnants of ancient mountain highlands the rocks of which have been repeatedly faulted, folded, and subjected to igneous intrusion. Not only are the rock structures that are concerned with the formation of hills of this class of great variety, but also the features differ as a result of development under unlike conditions of climate. In most hill regions of complicated structure, differential weathering and erosion in unlike rocks are the cause of the principal features of relief. In some it is the structural features, such as extensive faults, which dominate the scene. In hill regions situated in the rainy low latitudes climatic conditions tend to unify surface features by minimizing the effects of rock character and structure, just as arid environment tends to emphasize those factors.

The unifying effects of rainy tropical climate are brought about mainly as a result of active weathering. Chemical decomposition of rock is so rapid that features which, in colder or more arid climates, would erode into angular summits here weather into rounded uplands. Owing also to active weathering and the leaching influence of ground water, the typical soils of the humid tropics are highly porous (635). Much of the abundant rainfall soaks into the ground, and the rain-soaked regolith tends to creep or slide. This process sometimes bares the rock upon the steepest upper slopes, but at the same time it tends to soften the transition from upland to lowland with deep accumulations of weathered material. This is notably true of hills eroded in massive granite rocks. In them the rounded form of the uplands is to be seen even in middle latitudes, as, for example, in the hills and low mountains of the southern crystalline Appalachians (Fig. 269).

Elsewhere, to a greater degree than in the rainy tropics, hill features and hill patterns are influenced by complicated rock structures. Basaltic lava flows may protect weaker rocks beneath and erode into tabular, mesalike hills, even in humid climates. Alternating masses of resistant and nonresistant crystalline rocks give rise to areas of interspersed hills and basins. Extensive fault scarps themselves produce ridges which are dissected by streams into hills, or their fault zones develop linear areas of weakness which streams find and degrade into valleys.

Because of the extreme variety of physical

conditions involved in the making of their features, hill regions of complicated rock structure are highly individual and may not readily be grouped into classes according to type. However, attention may be directed to certain hill regions, the features of which will serve to illustrate some kinds of hill relief which are distinctive but which are of much more complex origins than the kinds previously described.

505. *The Crystalline Appalachian Highland of the South*, popularly known as the Blue Ridge Mountains, is comprised of igneous and metamorphic rocks of great age and structural complexity. Formerly it was a peneplain, a remnant of ancient mountains. Following reelevation, it has again been much eroded. In part of its broader and higher portion the region has a local relief of more than 2,000 ft., and its surface has the characteristics of low mountains. Most of its area, however, is a hill region of great irregularity, its various rocks having been weathered and eroded in different ways. Espe-

Fig. 268. Looking from the air along the crest of a ridge in the folded Appalachians. The river cuts the ridge at right angles and has made a water gap. The fields of the cultivated valleys are snow covered while the wooded ridge shows dark. (*Photograph by Fairchild Aerial Surveys, Inc.*)

Fig. 269. Rounded forms resulting from weathering and erosion in massive granites. A valley in the crystalline Appalachians of North Carolina. (*U.S. Geological Survey photograph.*)

Fig. 270. The subdued relief and eroded basins of the crystalline Appalachians in western North Carolina. (*Photograph by Cline.*)

cially toward the western margin of the region, some rocks of great resistance stand out as ranges of mountains and have steep bare slopes. A much larger part is eroded into hills of rounded summits and subdued relief, the flowing contours of which are well mantled with regolith and clothed with timber (Fig. 270).

506. *The California Hill Region of Linear Faulting.* The California Coast Ranges, especially those south of San Francisco, are comprised of sediments of several kinds and degrees of resistance, together with some igneous and metamorphic rocks. They have been severely folded and are arranged in a parallel ridge-and-valley pattern in some ways like that of the Appalachian ridge-and-valley region. However, the California hills have been subject to much more recent faulting and less folding than the Appalachians, and many faults, more or less parallel, traverse the region. Some of the faults are very long, one of them more than 500 miles, and they bear a close relation to the positions and arrangement of the linear valleys. The intervening ridges are developed on the more resistant sedimentary rocks.

507. Subdued Volcanic-hill Regions. In many parts of the world specific hill regions owe their elevation wholly or in part to the superior resistance of some form of intrusive or extrusive igneous rock. In the rainy tropical climate of the Guiana Highlands, where rounded uplands are usual, there are mesalike hills of sedimentary rocks protected by capping layers of igneous rocks, the result of former lava flows.[1] In the High Plains of the United States, the Black Hills are carved from a dome-shaped uplift caused by a batholithic intrusion. The igneous rock is exposed in the central area of the hills, which have a local relief of about 2,000 ft. The Palisades of the Hudson River and the Watchung Ridges, near New York City, owe their existence to the differential erosion of ancient basaltic intrusions.

In the Central Highland of France and the Eifel of western Germany are hill regions of a type found in modified form in other parts of the world also. Upon a platform of older rocks are the remains of lava flows and volcanic cones. Erosion has long since modified these surfaces but has not entirely removed the volcanic features. Subdued volcanic cones remain, and also domelike hills which are the weathered stumps of the lava cores or plugs that led to the former volcanic outlets (Fig. 271).

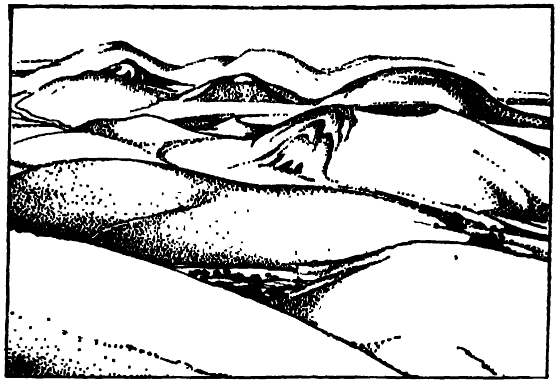


Fig. 271. Domelike hills in central France that are the remnants of ancient volcanic cones. (*After a photograph by Tempest Anderson.*)

508. *The Central Highland of Germany* is a hill and plateau region resulting from the stream dissection of an upland which is underlain by various rock types. Some are relatively young sedimentary rocks and nearly horizontal. Others are ancient crystalline masses, the remnants of former mountains, and some are igneous. The major hill regions include the highlands between the Rhine and Weser rivers, the Harz Mountains, the Thuringian Forest, and the hills which lie along the boundary between Germany and Bohemia.

509. The Great Hill Region of Eastern Asia. Of all the hill regions of the world, that of eastern Asia is most extensive and least well known. It includes not only the large mainland areas in Siberia, Manchuria, and Central and South China, but also most of Korea and Japan. Within its scope are rocks and structures of such diversity that it includes hill regions of many kinds of features and patterns of arrangement. Included within and almost completely surrounded by the hills of western China lies the famous "Red Basin" of Szechwan. This fertile and densely peopled area (Fig. 382) has

[1] R. A. Liddle. "A Geology of Venezuela and Trinidad." P. 7. J. P. MacGowan, Fort Worth, 1928.

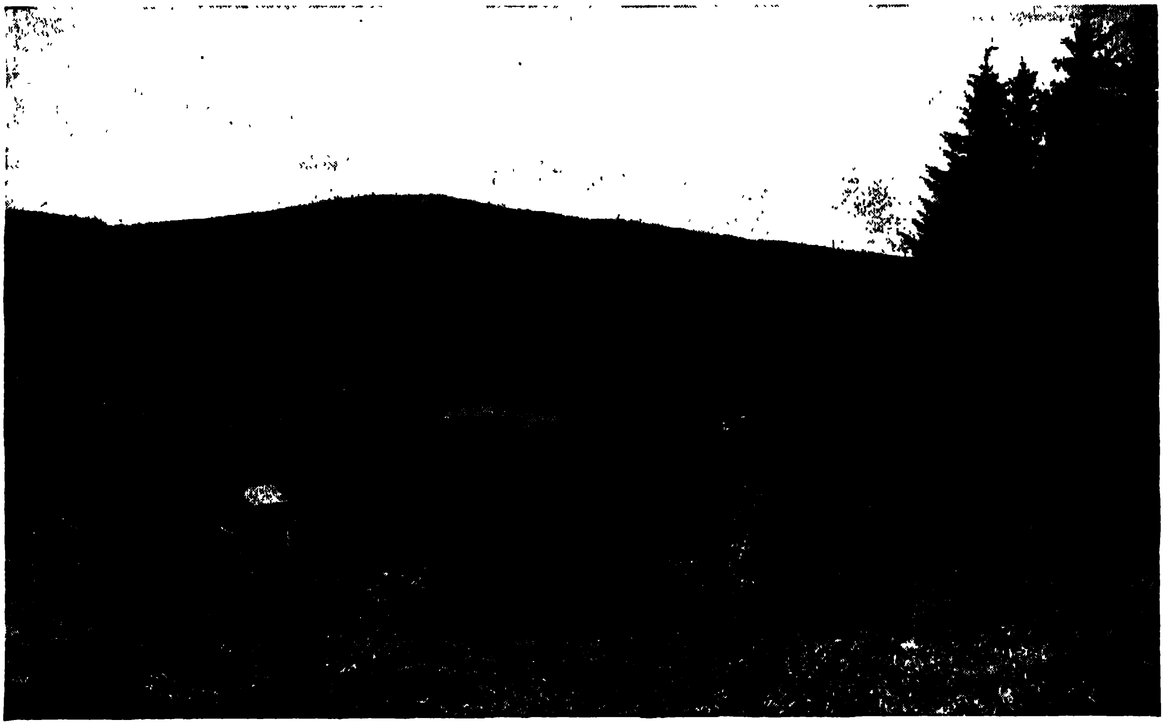


Fig. 272. The flowing contours of an ice-scoured hill region in Vermont. The hill features are subdued, and the valleys are drift mantled. (*Photograph by Underwood and Underwood.*)

been eroded in red sandstones by the Yangtze River and its tributaries. The river makes its escape across the eastern hill-land rim of the basin through the narrow and difficult Gorges of Ichang. In the large area of South China are strata of various ages, much faulted, in places folded, and interspersed with ancient, metamorphic crystalline rocks. The large human population of that region is distributed through the limited valley and basin areas among the hills.

Ice-scoured Hill Regions

510. The Characteristics of Ice-scoured Hills. In a previous consideration of ice-scoured plains (Chap. 16) the features resulting from ice erosion were described. Within the areas of continental glaciation there were hill regions also in which the original features, caused by an earlier stream erosion, were of a greater order of magnitude than those of the plains. High as they were, however, these hills did not greatly exceed the thickness of the continental ice sheets. Except for occasional rock masses, which may have projected in the form of nunataks through the glaciers, they were engulfed and overridden. The effect of ice scour upon the hill features is pronounced, whether the original features were stream-eroded portions of ancient crystalline highlands or of maturely dissected sedimentary uplands. The intricate patterns caused by gullying were erased, and there were substituted rounded features generally devoid of pinnacled promontories or sharp contours (Fig. 272). Mantles of regolith were swept away, and their place taken by thin stony soils or bare rock. Some of the ice-shaped hills show the steepened lee slopes of *roches moutonnées* on a scale that produces landscapes of scenic grandeur in spite of relatively small actual relief. Associated with the scoured and rounded hills are broad open valleys, usually thin-soiled and boulder strewn. Agricultural land is scant and poor, save in areas of more than usual morainic accumulation.

were first greatly deepened by ice scour and then partially filled with morainal and glaciofluvial deposits which flattened their bottoms and made them much more suited to agriculture (Fig. 274). In some of the valleys morainal dams have obstructed the present drainage and thus have created long, narrow lakes which are called the Finger Lakes (Fig. 275).

512. The Shore Features of Hill Lands. The shorelines of hill lands are different in many significant ways from those which characterize the meeting of plains with the sea. The steep and often serrate shores of hill lands commonly are bordered by sea bottom which slopes less gently than the continental shelf that borders plains. Shore features developing after the emergence of such coasts are likely to be characterized by great regularity, as are those of the coasts of emerging plains. However, the deeper waters offshore are less likely to provide conditions suitable to the formation of offshore bars and lagoons. Features resulting from the submergence of narrow and steeply sloping coastal valleys are likely to be of greater number and finer detail than are those of the coasts of submerged plains. Indeed, it is from the many

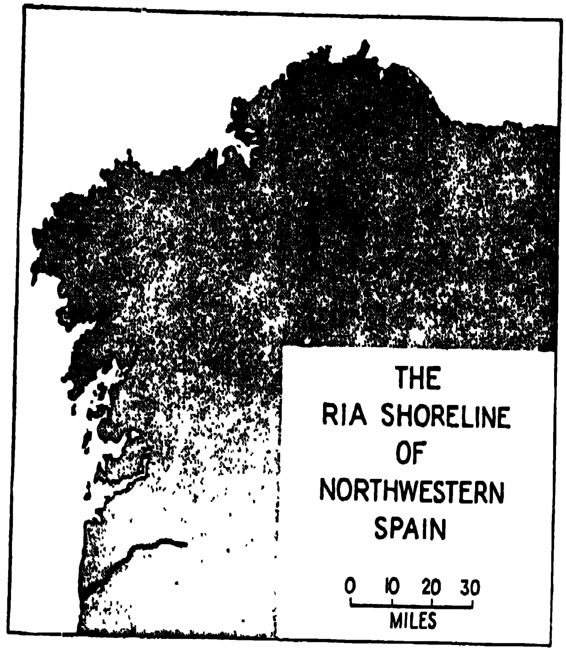


Fig. 276

parallel bays (called *rias*) on the hill-land coast of northwestern Spain that the term "ria shoreline" is derived (Fig. 276). The shorelines of hill lands have, in fact, much in common with those of mountain lands, and further discussion of them is reserved for that connection (541).

CHAPTER 21: *Mountains*

513. The Distinguishing Features of Mountains. Mountains, like hills, are distinguished from plains and plateaus by the smallness of their summit areas and the large proportion of their surfaces in steep slopes. Yet mountains are more than enlarged hills. In general they have greater relief and are more massive than hills; they have more rugged contours; and their surface features are more complicated in pattern. However, mountains are of wide variety in size and form. Great mountains are easily recognizable as such, but it is not easy, neither is it usually essential, to distinguish between low mountains and hills. Summit elevation above sea level is not significant, since even the bases of both hills and mountains in the far interiors of continents often are many hundreds of feet in elevation. A better basis of distinction is the criterion of local relief, previously used. A region does not have truly mountainous features unless the local relief exceeds 2,000 ft. That arbitrary limitation excludes from the list of mountain regions many areas of rough surface which locally are called mountains.

Above the lower limit of 2,000 ft. of local relief, here established as distinctive of mountains, are several possible classes of mountains. Four are suggested which may be delimited, as was done for plains, in terms of the maximum difference in elevation to be found within a horizontal distance of about 10 miles. The classes follow: (*a*) *low mountains*, having local relief of 2,000 to 3,000 ft.; (*b*) *rough mountains*, having local relief of 3,000 to 4,500 ft.; (*c*) *rugged mountains*, having local relief of 4,500 to 6,000 ft.; and (*d*) *sierran mountains*, having local relief of more than 6,000 ft.

Although steep slopes are among the distinguishing features of mountains, few of them are in fact so steep as popular belief would make them. The average slope of most great mountains probably does not exceed an angle of 20 or 25° from horizontal. A few exceed 35°, especially near their summits, where erosion proceeds rapidly along joint planes. The fact that mountain slopes commonly are made up, stairlike, of gentle inclines separated by abrupt rises or sheer cliffs has led to a popular exaggeration of the extent of the latter. Seldom is the sheer or overhanging mountain precipice more than a few score feet in height. The great and seemingly vertical walls hundreds of feet high found in some mountains are not vertical. In fact, they seldom exceed angles of 70° and are capable of ascent, at least by the animals whose habitat they are.

Several of the distinguishing features of mountains conspire to make them the least habitable of the four major groups of landforms (388). Narrow valleys and the large proportion of land in slope limit the area of tillable land to a small part of the total. Steep slopes mainly are stripped of their regolith, and where soil is present it is in constant danger of destructive erosion if disturbed by the plow. Forests and grass serve to utilize the soil on slopes and to aid in its retention. They are, therefore, among the most important of potential mountain resources. The conditions of mountain origin that give rise to complexity of rock structure commonly give rise also to mineral ores, and these may be added to the list of mountain resources having potential value for human use. So also may the potential water powers created by abundant precipitation and high stream gradients. Moreover, mountains adjacent to great centers of

Fig. 277. The crest line of a linear mountain range in Colorado, showing some of its peaks, saddles, and lateral ridges or spurs. The crest is a part of the Continental Divide.

population on plains have large actual or potential use as playgrounds. One reason for this is their great height and the modification of climate that arises therefrom. Another is the variety and beauty of their erosional and drainage forms. A considerable part of the population of the Alps and some other mountains subsists upon income derived from those who come to view mountain scenery or to enjoy mountain climate or mountain sports.

514. The Distribution of Great Mountains. Attention has been called previously to the probable relation between the tectonic activity of the regions of the Pacific Ocean border and other localities and the formation of mountains (350). The major regions of mountain distribution, shown in Plate V, emphasize that relationship. The great mountains of the world, the Andes, those of western North America, eastern Asia, the Himalayas, Caucasus, and Alps all lie within or upon the margins of areas of known crustal instability. It may well be that they are the broken and crumpled margins of segments of the earth's crust which have, as units, recently undergone, or are now undergoing, adjustments of elevation.

515. Classes of Mountain Features. A combination of diastrophic and volcanic forces, applied along the extensive and somewhat indefinite margins of crustal segments of the earth, has produced mountain uplifts of great variety in shapes, sizes, and arrangements. These are attacked by the agents of gradation, even as they grow, and are carved into equally varied features. The features are known, according to their respective sizes and arrangements, by such names as cordillera, system, chain, group, range, ridge, and peak.

A mountain *peak* is ordinarily a feature of a minor order upon a range, but in some instances, such as the great isolated volcanic cones, one of them stands alone and comprises the whole mountain mass. A mountain *range* is an arrangement, usually somewhat linear, of many peaks, ridges, and their included valleys (Fig. 277). Ordinarily the term range is applied to mountains that have a general unity of form, structure, and geologic age. The term *group* is sometimes

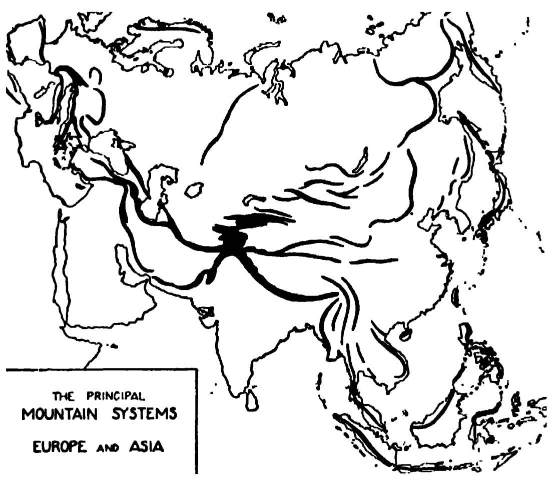


Fig. 278

used to describe peaks and ridges of rangelike size but not typically rangelike in shape. Such are the nearly circular, nodal, or massive patterns of peaks and ridges resulting from the erosion of laccolithic igneous intrusions.

Several associated ranges are referred to as a *mountain system* if they have some unity of position, form, or structure but are separated by trenches or basins. The Rocky Mountain system is an example. The term *cordillera*, although it originally meant an extended range or chain, has come to be applied to a large regional grouping of mountain systems.

516. Cordilleran Regions. Most of the great mountains of the earth are found in four cordilleran regions (Plate V). They are (*a*) the North American cordillera, which includes the Rocky Mountain and Sierra Madre systems, the Basin Ranges, the Alaska–British Columbia Coast Mountains, the Cascade–Sierra Nevada systems, and the Coast Ranges; (*b*) the cordillera of the Andes; (*c*) the cordillera of southern Europe, which includes the Carpathians, the Alps, the Pyrenees, and the mountains of Spain and northern Africa; (*d*) the Asian cordillera, which is comprised of the Himalaya, Kunlun, Tien Shan, and Hindu Kush mountains, which converge upon the nodal group of The Pamirs, together with the Caucasus Mountains and intermediate ranges.

The arrangement of the members of the great cordilleran groups with respect to each other, to the shapes of the continents in which they lie, and to the plains and plateaus adjacent to them should be studied with the aid of an atlas. The included mountains show by the frequent occurrence of faulting and earthquakes or volcanic activity that many if not most of them are young and even now in the process of growth. In other parts of the same continents certain ancient mountains, now reduced by erosion, indicate the existence of other cordilleran groups in earlier periods of earth history.

517. Mountain systems are significant in the realm of human affairs, directly because of the barriers that they interpose upon the movements of people and indirectly through relation to the distribution of climatic and other natural phenomena. The effectiveness of mountain barriers largely depends upon the height, continuity, number, and arrangement of the mountain forms. These conditions in turn depend upon (*a*) the character of the rocks involved in the mountain uplift, (*b*) the nature of the processes that brought about the uplift, and (*c*) the climatic environment under which erosion has progressed and the stage of completion to which it has been carried.

The patterns of arrangement of the great mountain systems profoundly affect the elements of landscape, both natural and cultural. Inspection of them, as they appear in an atlas, will show how generally they are deployed upon the earth's surface in broad arcs. This pattern is exemplified by the Himalayas and is common in the systems of Asia (Fig. 278). Other examples are not hard to find. The Carpathians, the northern Andes, the ranges of Alaska, and others show it clearly. Comparison will indicate that not a few political and other cultural boundaries conform to these curved lines.

518. Mountain Ranges. The ranges that comprise the world's major systems, chains, and groups of mountains differ widely in their patterns of arrangement. Several recognized patterns result from the erosion of as many different classes of tectonic structure. Four of the major patterns may be noted, as follows: (*a*) roughly parallel ranges resulting from the dif-

ferential erosion of strata that have been arched, wrinkled, or folded, and faulted by the forces of lateral compression. In such mountains some of the major longitudinal valleys may be of structural origin, the bottoms of synclinal folds. More commonly they result from differential erosion, certain of the more resistant rocks standing in relief as the mountain ranges. (*b*) Isolated or widely spaced ranges that are simply faulted as the result of lateral tension. Some of these are of great size; others are small. Some are tilted by a succession of faults along a single plane. Others are tilted horst blocks (Fig. 138). Upon any of them erosion is certain to have wrought great change of shape before they attain mountainous proportions. (*c*) Massive mountains with radial or featherlike range patterns resulting from the erosion of domed structures which were caused by laccoliths or other giant intrusions of igneous rock. The overlying sedimentary rocks upon such an intrusion may be almost entirely removed by erosion, and the ranges and valleys of radial pattern eroded in the massive rocks beneath. However, the eroded edges of the sedimentary formations sometimes lie as encircling ranges of cuestaform foothills about the flanks of the principal mountain mass (Fig. 142). (*d*) Conical mountains, or ranges comprised largely of such mountains. These are cones produced by volcanic extrusion.

519. Range Patterns in Various Mountains. The erosion of young mountains, the uplift of which was brought about by folding with associated faulting, produces systems with more or less parallel ranges, the intervening valleys resulting from differential erosion. In some places the erosion has been so great that the resistant rocks of anticlinal folds have been removed, and the valleys are cut in the less resistant formations beneath. Between the valleys are mountains in which the attitudes of the rocks show them to be the remnants of former synclines (Fig. 139). Other of their valleys are structural rather than erosional, some of them due to downwarping and others to faulting, although even those features usually are modified to some degree by gradational processes.

Examples of mountains of somewhat parallel arrangement are numerous. Detailed maps show that the Carpathians, Atlas, Himalayas, Andes, and other mountains contain ranges the major axes of which trend in the same general direction. Some of the ranges of the Rocky Mountains show a significant alignment also. Where they cross the Canada–United States boundary, they are comprised of roughly parallel ranges which are separated by two linear "trenches" of remarkable length. Farther south, the ranges of Colorado are more widely spaced and are separated in part by broad basins, locally called "parks." The Alps are the eroded bases of faulted and folded strata in the formation of which the compression was so great that many of the folds were crumpled and overturned, Their structure is, therefore, highly complicated. But certain of their longitudinal valleys which are of tectonic origin are to be seen on any good map of those mountains (Fig. 5).

Some great mountain ranges, and many smaller ones, appear to have been formed principally by faulting. The 400-mile-long range of the Sierra Nevada Mountains of California is carved by streams and glaciers in the edge and upland of a faulted block the escarpment of which, in places more than 2 miles high, faces eastward and the upland of which inclines less steeply westward (Fig. 135*C*). The bold west-facing front of the Wasatch Mountains in Utah is likewise the result of displacement along a fault zone, the gentler slopes being generally toward the east (Fig. 137). Some of the many adjacent Basin Ranges also are eroded fault blocks. They show a general north-south alignment and are separated by broad bolsons (Fig. 229). Faulted block mountains of similar type and linear arrangement are found in a large region which includes Palestine, Arabia, and part of eastern Africa. Some of them are so freshly faulted that the latest additions to their growth remain almost unmarred by erosion. In all of them, however, the crests are deeply scarred, even in the arid climates of the Great Basin and Arabia.

Not all linear mountain ranges, however, are to be ascribed to diastrophic causes. In some,

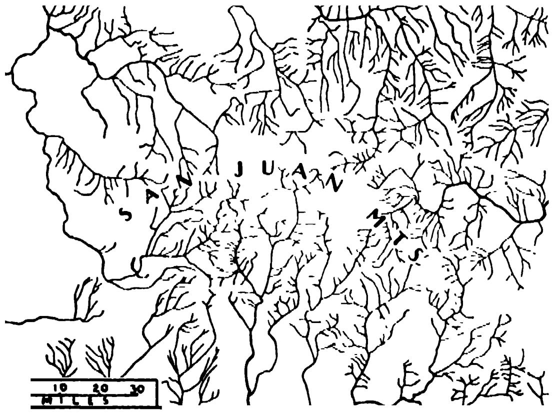


Fig. 279. Radial pattern of drainage in the San Juan Mountains, Colorado.

faulting and folding do appear to have been the principal causes; but in others the cause seems to have been vulcanism. Certain mountain ranges are largely composed of volcanic materials, erupted along lines of weakness in the earth's crust. The cones thus formed assume somewhat linear arrangement, and the ranges may be considered volcanic even though they rest upon platforms of older rocks. The islands of Java and Sumatra and others of the East Indies are of that origin. The narrow island of Java, for example, contains nearly 20 active volcanoes. Several of the principal peaks (Mounts Hood, Adams, Rainier, Baker, etc.) and many of the lesser ones in the Cascade Range of the United States also are inactive volcanoes in roughly linear arrangement.

Mountain groups that are of volcanic or laccolithic origin commonly have massive or compact rather than linear forms, and a few are roughly circular in outline. The eroded ridges and valleys of some of them have intersecting, featherlike, or radial patterns or some modification of the radial relation. The Henry Mountains of Utah, and other smaller groups in the region, are examples of laccolithic mountains (Fig. 142). The sediments, updomed by igneous intrusion, now are eroded away from the uplands and appear only as encircling cuestaform ridges, as they do also about the Black Hills of South Dakota (491). The San Juan Mountains of Colorado are the eroded remnants of a high plateau composed of lavas and volcanic ash. Streams and glaciers have carved it into a mountain mass of great ruggedness and nearly radial pattern of drainage (Fig. 279).

520. Volcanic Cones. In addition to the mountain masses caused by volcanic intrusion or extrusion, there are many notable examples of single volcanic mountains or volcanic cones, some of which are active and occasionally in violent eruption. Their general distribution has been noted previously (Fig. 143). Some of the great volcanoes are surrounded by lesser cones and also by mountain peaks carved by erosion in the massive uplifts of which the volcanoes are a part. Others stand alone. Some volcanoes of the type first noted have great summit elevation, but they do not all have great local relief, since they stand upon foundations of great altitude. A number of those that stand alone upon lowlands are famous for their beauty of form. Although not many of them reach high altitudes, some have great local relief because they rise practically from sea level. The peak of Fuji (not now an active volcano), in Japan, is not quite 12,400 ft. above the sea, but the mountain is a tall and striking landscape feature because it stands alone and reaches its full height within about 15 miles of the sea (Fig. 280). Some other cones of great fame or beauty of form are Mount Egmont (not active), in New Zealand; Mount Mayon, in southern Luzon; Etna, in Sicily; and Vesuvius, near Naples. Such famous American volcanic cones as Mounts Rainier, Hood, Shasta, Popocatepetl, and Chimborazo (20,700 ft.) are much higher but are not more inspiring sights. Even the higher Hawaiian cones (10,000 to nearly 14,000 ft.), although they are tall, are of less striking aspect than the cones first mentioned because of their flattish or domed profiles, the slopes of which lie at low angles which generally are between 4 and 10°.

521. The Features of Volcanic Cones. Reference has been made to the steep slopes characteristic of volcanic cones that erupt acid rocks (352). Most of the world's volcanoes are of that type, but their cones, while they are steeper than those of the Hawaiian type, are by

CHAPTER 22: *Water Resources of the Land*

548. The Variety of Uses of Water. Water exceeds any other earth resource except air in the urgency of its need and in the quantity used. So many and so vital are the purposes for which it is required and so varied are its qualities and conditions of supply that several fields of technical science are concerned with its abundant, continuous, and safe provision. The waters of the land are derived, either directly or indirectly, from atmospheric precipitation. For that reason, regions of abundant precipitation usually, but not always, have abundant supplies of water, and their inhabitants are able to use it lavishly. In arid regions water is the element of first importance in restricting the settlement and use of land, and the supply of it is used with utmost economy.

Water supplies and water bodies are useful to man in many different ways, some of the most important of which are (*a*) in domestic supply, (*b*) for industrial processes, (*c*) for the irrigation of crops, (*d*) for the production of mechanical power, (*e*) as routes of inland transportation, and (*f*) in the added attractiveness that they give to scenic or recreational areas. The use of water for drinking and household supply ranges from a small daily ration among the nomadic people of arid lands to the daily per capita allowance of 15 to 60 gal. which is provided in American cities, the amount varying with the classes of residential property. That use certainly is the most important to mankind, but there are other important urban requirements. Modern manufacturing establishments, such as steel mills, textile dyeing-and-finishing plants, and paper mills are large users of water. A steel mill, for example, is said to use in its various processes about 150 tons of water for each ton of finished steel it produces.[1] A choice of site for such an establishment often is made because of the availability there of an abundant supply of water having the requisite chemical properties or degree of pureness. For these uses great manufacturing cities must supply much more water per capita of their population than is used in the homes. The average total consumption of water for all kinds of uses, in 90 cities of more than 100,000 population in the United States, is the equivalent of about 125 gal. per day per inhabitant. Per capita consumption in the principal European cities averages hardly one-half that amount. The municipal system of Chicago supplies each day to its homes and factories an amount of water equivalent to 270 gal. for each of its residents.[2] That city has the highest per capita rate of consumption of any in the United States, and doubtless much of the water is wasted because of the abundant supply close at hand in Lake Michigan.

549. Sources of Water Supply. The large quantities of water required by modern urban and industrial centers are obtained from wells, springs, large lakes, and large rivers but even more generally from small streams the drainage of which is stored behind dams to create municipal reservoirs. Only about one out of four of the principal American cities obtains its water supply from wells. Most of the remainder, and especially the largest cities, use surface waters. However, about 60 per cent of the total population of the country live in cities of less than 25,000 population, in villages, and on farms

[1] *Steel Facts*, June, 1948. P. 6.

[2] "Report of The National Resources Board." P. 332. U.S. Government Printing Office, Washington, D.C., 1934.

where ground water, obtained from wells and springs, is the principal source of supply. For the irrigation of crops, surface waters are much more important than ground water, since the latter source supplies only about one-fourth of the irrigation water used in the arid sections of the United States. Although the conditions found in the United States with respect to water supply are not representative of those to be found in all parts of the world, they give an indication of the required volume of this essential resource and some measure of the relative importance of the sources from which it is obtained.

The Ground-water Supply

550. The Availability of Ground Water. It has been noted previously that a part of the precipitation is captured and prevented from flowing immediately into streams and the seas when it percolates downward into the pore spaces and crevices of the regolith and the underlying rocks. It has been noted too that, under ordinary conditions, the lower levels of these pore spaces are filled with water and that the top of the saturated zone is called the *ground-water table* (365). The water stored below the ground-water table is the source of supply for springs and wells (Fig. 146).

The availability of ground water is not everywhere the same. In regions of abundant and well-distributed precipitation the pore space in the earth is likely to be well filled, but in arid regions the rapid evaporation of moisture and the high percentage of runoff following the infrequent, but often heavy, rains do not permit of a deep penetration of ground water. The supplies in arid regions are, therefore, mainly such as move slowly, deep underground, from more humid regions. Frequently they are limited in quantity and are to be had only in a few localities, and those places take on critical importance in the migration and settlement of people. Even in humid regions ground water is not everywhere abundant. A copious supply depends not only upon abundant precipitation but also upon (*a*) earth materials of sufficient *porosity* to absorb and store a large quantity of water and (*b*) the existence of pore space, bedding planes, fracture planes, or other avenues providing sufficient *permeability* to permit a relatively free underground movement of water from a large storage area to the well or spring from which it is being removed. Beds of gravel, sand, loosely compacted sediments, porous sandstones, and thinly bedded or cavernous limestones provide these conditions. Compact clays and shales, massive and little-fractured igneous rocks, and some other formations provide but little storage capacity for water and but little facility for its underground flow. Springs in such rocks seldom are abundant, and wells are difficult to construct and limited in flow.

551. Pore Space for Ground Water. In sandstones the pore space capable of being filled by water commonly exceeds 20 per cent and sometimes reaches 40 per cent of the volume of the rock. In unconsolidated earth or glacial gravels the figure is much greater. In massive crystalline limestones there often is 5 to 10 per cent of pore space; and in chalky or cavernous limestones there is much more than that amount. In dense igneous and metamorphic rocks the pore space is much less. In solid granites it seldom is more than 1 per cent; and in some metamorphic rocks it is said to be less than one-half of 1 per cent. In such rocks the pores are so small they they do not readily yield the little water that they contain. Numerous joint cracks or structural planes in dense rocks greatly increase both their water-holding and water-yielding capacities. However, some large regions are underlain by massive and little-fractured igneous and other crystalline rocks from which the recovery of ground water is expensive and seldom adequate.

552. The Qualities of Ground Water. No ground water is free from dissolved mineral, but the nature and quantity of the chemical salts carried in solution differ widely from region to region. A few dissolved minerals, such as sulphur or iron, impart to water a disagreeable taste or render it unfit for certain industrial processes. Some minerals give tonic, laxative, or other desirable medicinal qualities. Among the most abundant of the soluble salts found in ground

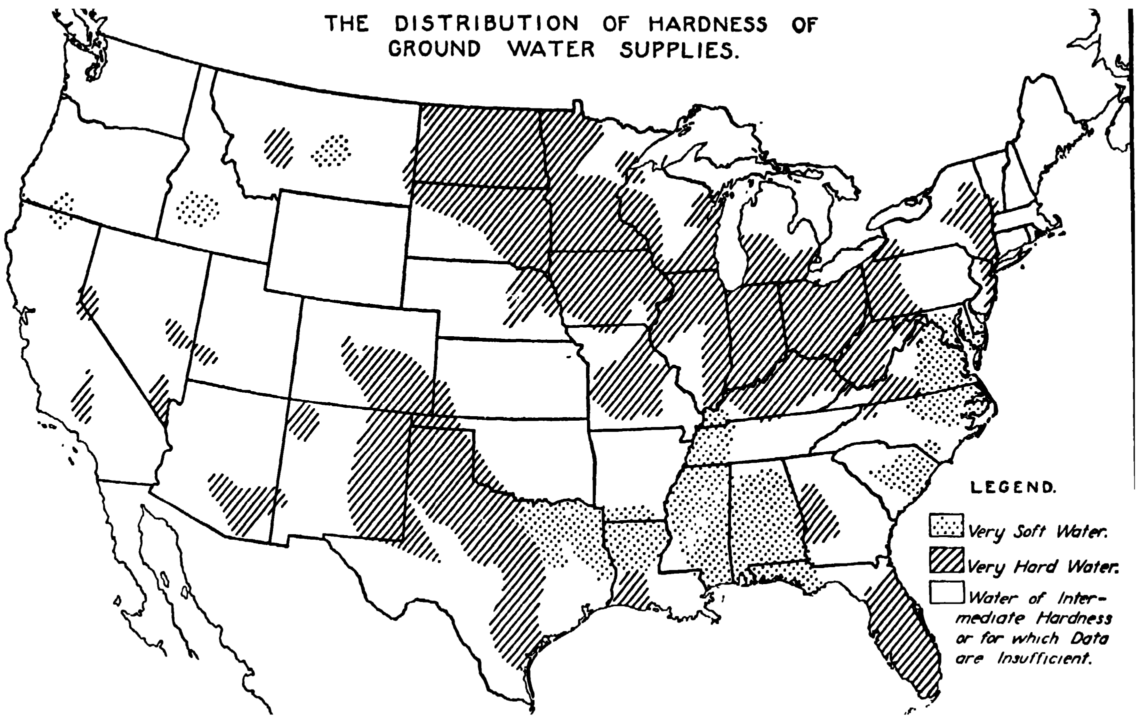


Fig. 299. (*After U.S. National Resources Board.*)

water are compounds of calcium (lime), sodium, and magnesium. In desert regions seepage waters commonly are charged with compounds of these and other salts to a degree that renders them almost, if not quite, unfit for human use. In the United States these are known as *alkali waters*. In humid regions most of the readily soluble sodium compounds have been removed from the upper horizons of the ground long since. However, limestones, lime-cemented sediments, and dolomites (336) furnish supplies of calcium and magnesium which, although they do not much affect the taste of water, give it the quality called *hardness* which does affect its domestic and industrial utility.

Ground water ordinarily has been filtered through the earth, sometimes for many years, before it is used. It is, therefore, relatively free from mud and other suspended materials.

553. *The Hardness of Water.* The amount or degree of hardness in water usually is expressed in terms of parts of dissolved mineral per million parts of water. Regions underlain mainly by ancient crystalline rocks or by highly siliceous sands or sandstones usually have not much available lime, and their waters may contain as little as 5 or 10 parts of hardness per million. These are the naturally "soft" waters. Water containing as much as 60 parts still is considered soft, but if it contains more than 120 to 180 parts per million it is considered "hard" water. In regions of lime-containing sedimentary rocks, well waters in common use contain 300 to 500 parts and, in a few places, as much as 700 to 800 parts per million (Fig. 299). Many wells in arid regions, and some even in humid regions, tap supplies of ground water so hard as to be unfit for use. Hard waters require "softening" when they are used with soap and present serious problems in certain industrial processes or in the supply of steam boilers. This is because of their chemical reactions and the undesirable precipitates that they form.

554. Springs. A spring is a concentrated natural outflow of water from underground. It may flow either continuously or intermittently (349), and its water may be either cold or warm, hard or soft. Springs result from a variety of

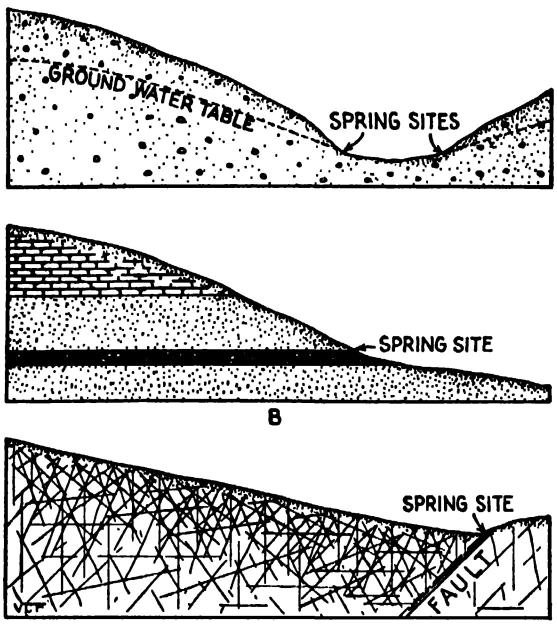


Fig. 300. Diagrams to illustrate some of the many possible conditions of surface, material, and structure that are related to the occurrence of springs.

conditions involving the position of the ground-water table, the configuration of the land surface, and the nature and structure of the rocks. Figure 300*A* illustrates the occurrence of a spring on the side of a valley which has been eroded below the usual level of the local ground-water table. Springs of that type are common in glacial drift and often are the main sources of supply of small brooks at the headwaters of rivers. After a period of protracted drought the level of the ground water that supplies such a spring may be lowered, and it will cease to flow until the water level is raised by the downward seepage of further rains. Figure 300*B* illustrates the site of a spring caused by the movement of water downward through porous formations and then horizontally along the top of an impervious rock layer. Sands, sandstones, or porous limestones, underlain by compact clays or shales, supply conditions of that kind and often produce many springs, all at about the same level. Figure 300*C* illustrates the manner in which water from a wide area of rocks, even those of low water-holding capacity, may be converged upon a spring by means of joint and fault planes. In some regions water thus collected is conveyed deep underground where it comes under the influence of hot igneous rocks and finally issues as hot, or "thermal," springs or even as geysers. The latter add to the scenic attractiveness of several regions in which they occur, such as Yellowstone National Park; Iceland; and North Island, New Zealand (Fig. 301). In those regions, geysers, the name of which is derived from that of one of the intermittent hot springs of Iceland, are resources of considerable value, because of the tourist business they bring. Hot water and steam from underground are used in a few localities as sources of heat and power. Some such localities are found in Italy, Iceland, and California.

Some springs drain water from far beyond the immediate localities in which they are found. Because they are outlets for considerable areas and draw upon large ground-water supplies some of them have large volumes and are perennial in flow.

555. *Large Springs.* Under certain conditions of underground drainage, springs attain the proportions of considerable rivers. That is notably true in regions of cavernous limestones or of porous lavas. In such rocks, ground water descends from the surface through numerous openings and ultimately converges upon an underground channel in some volume. There are in the United States about 60 springs with sufficient flow so that each would supply all the water required by a city of ½ million inhabitants. There are at least a half dozen that flow with sufficient volume so that any one of them would supply a city of 2 million inhabitants.[1] Most of the large springs of the country are included in four regions. They are the limestone areas of (*a*) the northern Florida karst and (*b*) the Ozark region of southern Missouri; and the permeable-lava regions of (*c*) the Snake River Valley of Idaho and (*d*) western Oregon and northern California (Figs. 302 and 303). Other regions of large springs are indicated in Fig. 302.

556. The Use of Spring Waters. In the United States are thousands of farmhouses and

[1] O. E. Meinzer. Large Springs in the United States. *U.S. Geol. Survey, Water Supply Paper* 557, 1927.

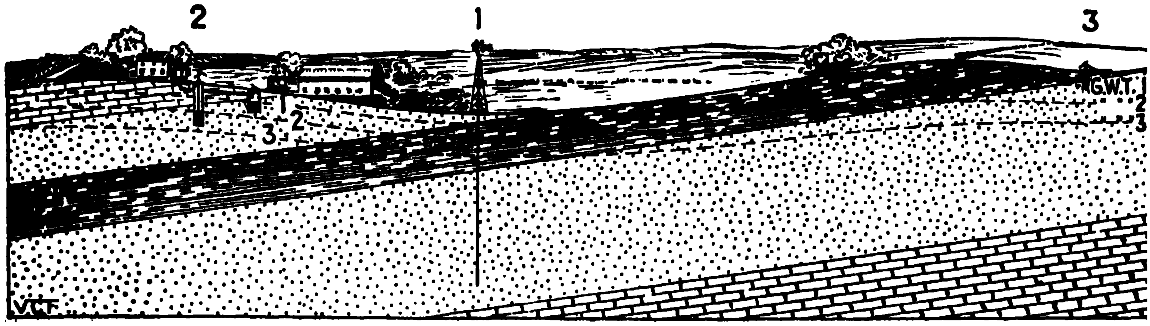


Fig. 304. The well numbered 2 is higher than that numbered 1 and appears to yield a safer water supply but, in fact, it does not because of the rock structures concerned. The stippled horizons indicate porous, water-bearing formations. The dashed lines show positions of the ground-water table: 1, in wet seasons; 2, ordinary level; 3, in dry seasons.

the lowest position of the water table and has never run dry; that numbered 2 is a dug well which reaches below the ordinary water table and has water at all times, except after periods of protracted drought; that numbered 3 is dry, except for a short time after a long period of rains.

A modern deep well, like that numbered 1 above, is made by drilling a small hole scores or hundreds of feet, through surface formations and the upper part of the ground-water zone, into the deeper waters of some known water-bearing formation, such as a porous sandstone. From a drilled well water must be lifted by a long pump rod through a pipe which is carefully encased to prevent the surface waters from seeping into the drill hole and thus contaminating the deep water supply. Figure 304 indicates that, while well 2 is situated higher up the slope than No. 1 and appears to be in a safer position with respect to pollution, it is in fact not so. The porous rock formation below the surface carries seepage from barns and cesspool directly toward the house well rather than away from it, as the surface slope would indicate. Many wells are located badly because of ignorance of the nature of ground-water movement and of the structure and permeability of the rocks that govern ground-water movement in the locality in which they are constructed.

The quantity of water from deep wells, as well as the quality, depends upon the nature of the underlying rock and its structure. If the well hole terminates in a thick porous sandstone of great areal extent and broad outcrop, it may yield an abundant and continuous supply of water. If the only rock beneath a locality is of the massive crystalline type, the water yield may be continuous but not abundant. The rock has so little pore and crevice space that its water content is small. The rate of flow into a well in dense rock is sometimes increased by using explosives at the bottom of the hole to shatter the surrounding rock and make numerous crevices through which the water of a larger area may flow in. However, some hard crystalline rocks are so low in water content that no device can bring about a sufficient flow to justify the very high cost of drilling deep wells in them. Shale rocks, although not hard, also commonly are compact, impervious, and "dry," but usually they are closely associated with other sediments which are porous. Wells in regions of cavernous limestones sometimes tap underground *streams* of water. Such wells may yield abundant supplies, but since the water has entered the underground channel directly from the surface drainage, some of it through sinkholes, it has had little natural filtering and is subject to pollution. It is likely to be little safer than the river waters of the same region, since the latter have at least been exposed to the bacteria-destroying power of sunlight.

558. Artesian Wells. Common use applies the term *artesian* to any deep drilled well from which water flows or in which the water level rises so near to the surface as to require little pumping. Originally the term was restricted to

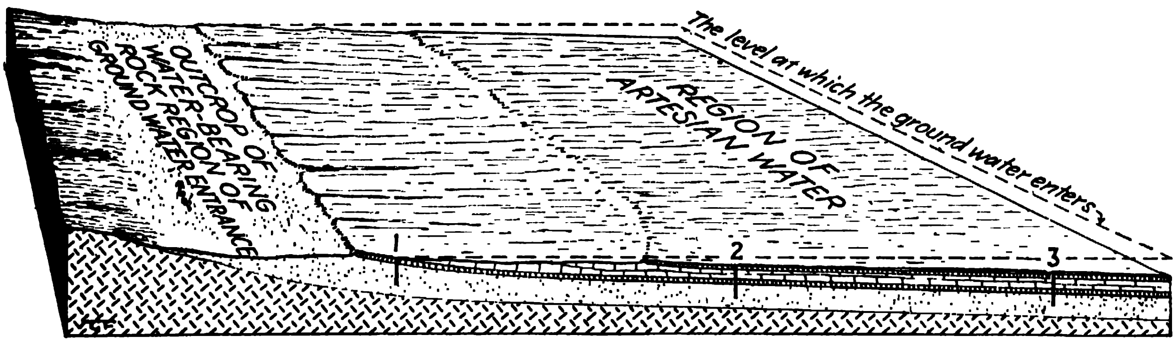


Fig. 305. A diagram to illustrate one type of artesian structure. The well numbered 1 (left) reaches the water-bearing formation, but its top is as high as the level of ground-water entrance, and it would require pumping. Wells numbered 2 and 3 should provide flowing water.

such wells as flow freely without pumping. Artesian wells are possible under any one of several sets of conditions of underground structure, one of which is illustrated in Fig. 305. The favorable situation must include the following conditions: (*a*) a water-bearing formation of sandstone or some other pervious material; (*b*) the pervious formation must outcrop or be exposed at the surface in a region of sufficient precipitation to fill it with water; (*c*) the formation must disappear at a low angle of inclination beneath a capping layer of some impervious rock, such as shale; (*d*) it must lead toward a region where the land surface is lower than it is at the exposed end of the pervious formation; and (*e*) there must be no free exit from the pervious rock at an elevation lower than the region of the wells. A well drilled through the impervious layer and into the water-bearing formation taps a supply that is under pressure owing to the weight of the water that is backed up in the higher end of the porous and pervious formation. Water will rise in the well bore or flow from the opening as long as the rate of addition in the outcropping area exceeds the rate of loss through wells and seepage. In a few regions saucerlike structural basins of concentric relief contain water-bearing formations which outcrop about the edges of the basin and incline from all sides, underneath other rocks, toward its center, where artesian water may be had in abundance. A structure of that kind is found in the Paris Basin (407). (The term artesian, applied to wells of this class, is derived from Artois, the name of a district in northern France.)

559. *Notable Artesian Structures.* Artesian water is obtained from favorable structures, which occur locally in a great many places, and from a few that cover areas of truly great extent. One of the latter is the northern Great Plains region of the United States. There a series of water-bearing formations, especially the Dakota sandstone, outcrop at considerable elevation near the Rocky Mountains and incline eastward, under suitable capping layers, toward the lower plains. They yield artesian waters far out in the eastern part of the Dakotas.

The dry lands of Australia also are blessed with artesian waters obtained from more than a half dozen favorable structures. One of these deserves its name, the Great Artesian Basin (Fig. 306). This is a broad synclinal structure, having a total extent equal to about one-fifth the area of the United States. In it pervious rocks, mainly sandstones, outcrop about the margins while its interior portion is buried beneath impervious clays and shales. The principal intake area lies in a large region of moderate rainfall west of the Great Dividing Range in eastern Queensland. The center of the basin lies beneath that arid region which includes southwestern Queensland and parts of the adjacent states. Some of its waters flow from natural springs, some from shallow wells, and some from deep wells; the deepest is more than a mile. Some of the nearly 9,000 wells flow freely and others require pumping, some yield cool

waters and others hot, some fresh and others saline.[1] Few yield enough to irrigate significant areas of crops, but they are most important in providing water for livestock and the pastoral occupants of these dry plains. Artesian structures are found also over large areas in northern Africa and central Argentina. There are many limited artesian structures and spring sites in American dry lands and those of other countries that furnish water for the irrigation of a few acres of crops in addition to that required for other uses. In these scattered bits of irrigated land may be recognized an additional class of oasis of much less individual importance than those previously noted (418, 425, 453, and 460).

Unfortunately, the flow of water in an artesian basin cannot be maintained at a higher amount than that absorbed in the catchment area, where the water-bearing rock outcrops. It is, therefore, capable of depletion. Thousands of flowing wells in the Dakotas and hundreds in Australia, and careless waste of water through them, have decreased the pressures in both regions until many wells now require pumping, and the flow of others is much reduced.

The Surface-water Supply

560. The Uses and Problems of Surface Waters. The economic utility of surface waters is so varied and the problems connected with them are so numerous that only a few of them may be touched upon. Surface drainage through streams and lakes is related to matters of economic concern such as soil erosion, flood control, power production, irrigation, municipal water supply, inland navigation, and the business of recreation. Out of these varied uses grow conflicts of human interest which lie beyond the scope of the elements of geography. However, the natural-resource qualities of surface waters may be examined briefly in their relation to some of these uses.

561. Surface Waters for Municipal Supply. Of the 300 principal cities of the United States, three-fourths are supplied with surface waters obtained from great lakes, large rivers, or more commonly, relatively small streams.[2] Generally, the surface waters are less hard than the ground waters of the same region, because they are derived in part from the immediate runoff of rain water (Fig. 307). In periods of drought the surface supply fails, and the streams, fed mainly by springs, have increased hardness, to the great disadvantage of certain industries the manufactural processes of which require relatively soft water. However, surface waters are likely to contain larger quantities of sediment and organic matter, including bacteria, than ground waters. For that reason many cities find it necessary to treat their water supplies (*a*) for the destruction of bacteria, (*b*) for the coagulation and flocculation of very fine sediment and colloidal matter, and (*c*) by filtration, to remove sediment. They must also build dams to create impounding reservoirs for the storage of water in flood seasons in order to maintain a uniform supply. The quality of surface water varies greatly from region to region.

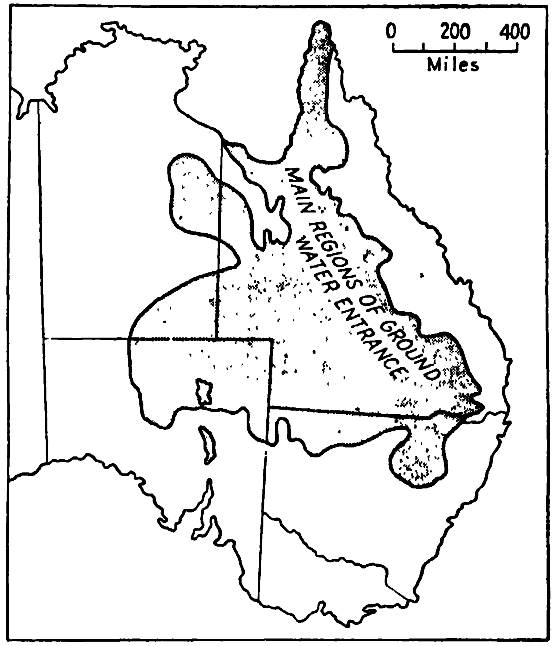


Fig. 306. The Great Artesian Basin of Australia. (*After James E. Collier.*)

[1] James E. Collier. Artesian Water and Australia's Pastoral Industry. *Scientific Monthly*, Vol. 40, pp. 117–129, 1945.

[2] "Report of the National Resources Board." P. 330.

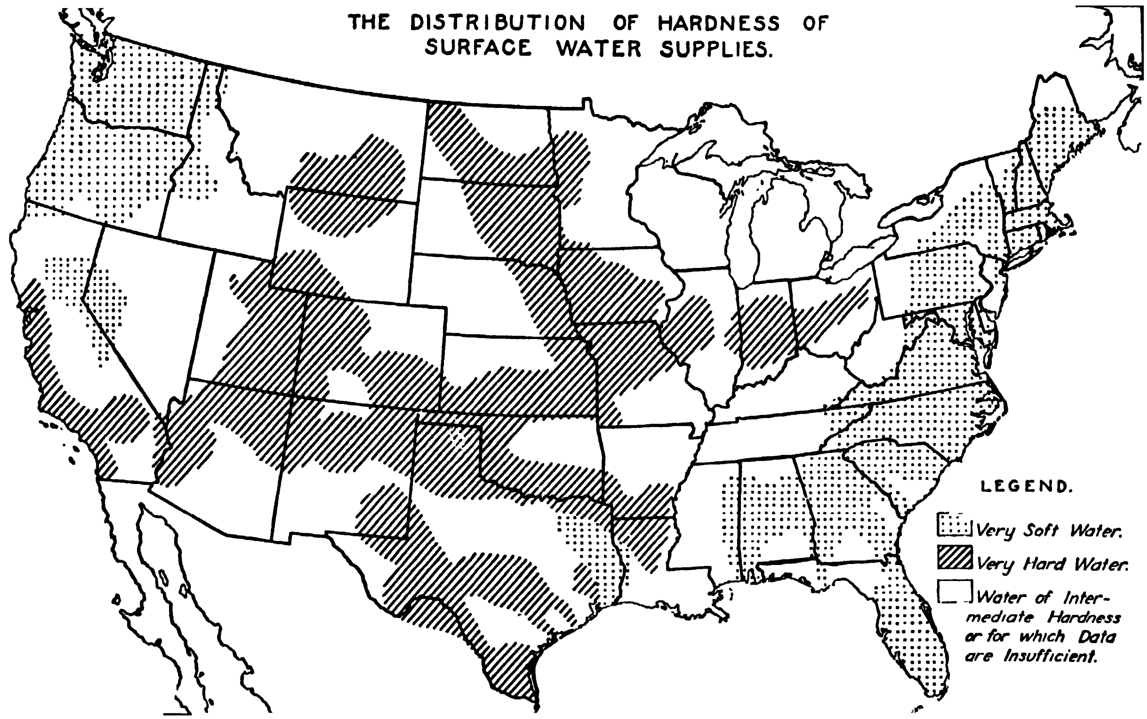


Fig. 307. (*After U.S. National Resources Board.*)

562. Waters Used for Irrigation. The soils of arid lands generally are abundantly supplied with the mineral elements of soil fertility and require only water and sometimes organic fertilizers to make them productive. Adequate supplies of water are not easy to obtain, for the actual water requirement of crops is large, and inevitably much is lost by seepage and evaporation in the course of getting it to the crops. In American irrigation practice, although the amount of water required varies with the region and the crop, it is customary to provide annually the equivalent of a layer 2 to 3 ft. deep over the entire area to be irrigated. To secure so much water every type of source is drawn upon (532), but, the world over, surface runoff supplies most of it. Except in the rice-growing monsoon countries of southeastern Asia, irrigation is most practiced in lands that have less than 20 in. of average annual precipitation. Since the water requirement of the crops grown is generally much more than that quantity, and since always there are losses in the processes of capture, storage, and transportation, it follows that the rainfall of a large area is required to provide water to irrigate a small area. From that fact it is necessary to conclude that only a small part of the dry lands of the earth ever can be irrigated (Fig. 308).

563. The quality of irrigation waters is not everywhere the same. Some, particularly that obtained from underground sources, is heavily charged with dissolved salts, certain of which are harmful to cultivated plants or to the structure of the soil. Such water when applied to the land sometimes leaves more soluble material in the soil, as a result of surface evaporation, than is removed through the drainage channels. This tends to increase the alkali content of irrigated soils and gradually to render them unfit for crops. Waters derived directly from mountain precipitation and the melting of mountain snows are particularly free from this defect and are much employed in the irrigation of alluvial fans upon the mountain borders. Some part of the irrigation water applied to the land, supplemented by a part of the natural rainfall, soaks into the ground, joins the ground-water

supply, and then commonly is recovered by pumping or by other means (409). It is then reused for irrigation unless, or until, the quantity of harmful salts dissolved during its stay underground renders it unfit for the watering of crops.

564. Physical Conditions Favorable to Water-power Production. Water has no inherent ability to develop energy in the same sense that it is able to quench thirst, supply plants, or cleanse fabrics. Its capacity to do work is attained by virtue of the solar energy which evaporates it and causes the wind to transport it onto the land, whence it is returned to the sea under the force of gravity. The essential conditions required to produce water power are *water* and *fall*, and within limits one of them may substitute for the other. A small volume of water falling a great distance may have the same capacity to do work as a great volume of water falling a short distance. Moreover, the former usually is capable of being more economically harnessed than is the great stream on a low gradient. Water power is, therefore, obtained at less cost from small mountain streams than from the great rivers of plains regions.

Several conditions of physical environment combine to furnish great water power and to make it economical to use. An ideal physical situation for water-power production might well include the following conditions: (*a*) *a large stream*, and (*b*) *a precipitous fall* in the lower course of the stream where the entire weight of the falling water may be harnessed at low cost. It is desirable that the stream be the drainage of a region (i) of large size and (ii) of abundant precipitation. It is also desirable (iii) that the precipitation be uniformly distributed throughout the year and (iv) that the runoff of the stream be further regularized by the natural storage of rain water in great areas of spongy forest floor, numerous swamps, or lakes.

565. Stream Flow and Potential Power Development. A regular stream flow is desirable for water-power development because fluctuation in flow produces irregular power capacity. Ordinarily, it is not economical to build a power plant capable of utilizing the maximum flow of an erratic stream. Many power plants have capacity to use only the minimum flow, since otherwise a large financial investment in power plant would be unproductive of returns during much of the year. The construction of dams and other works for the storage of water tends to unify stream flow by capturing flood waters and holding them for use in the season of low water, as has been done, for example, in the Tennessee Valley (Fig. 309).

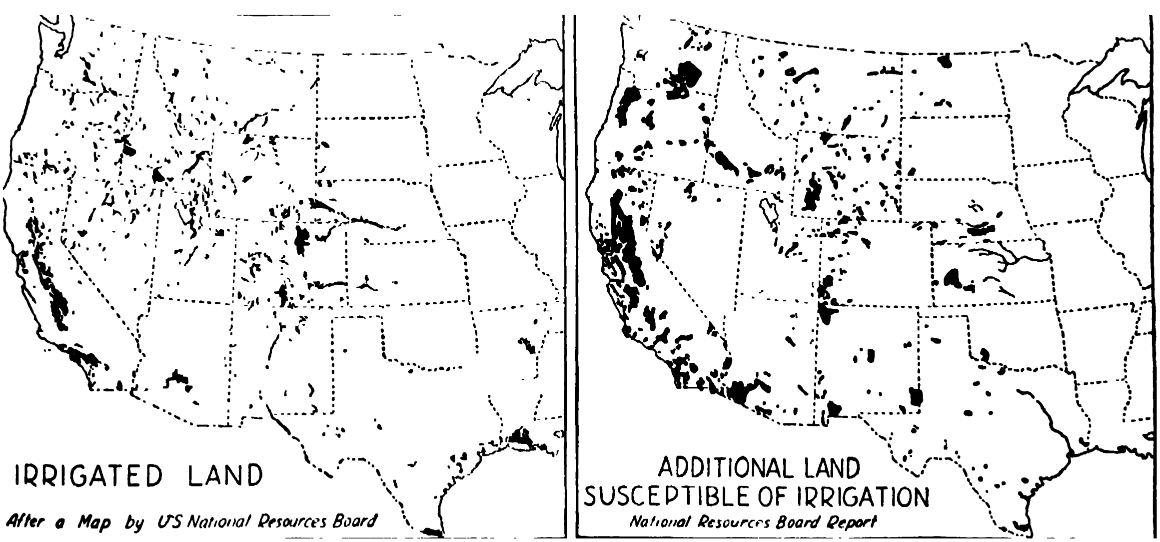


Fig. 308. The irrigated land and that susceptible of irrigation taken together do not comprise a very large part of the total area of the arid and semiarid West.

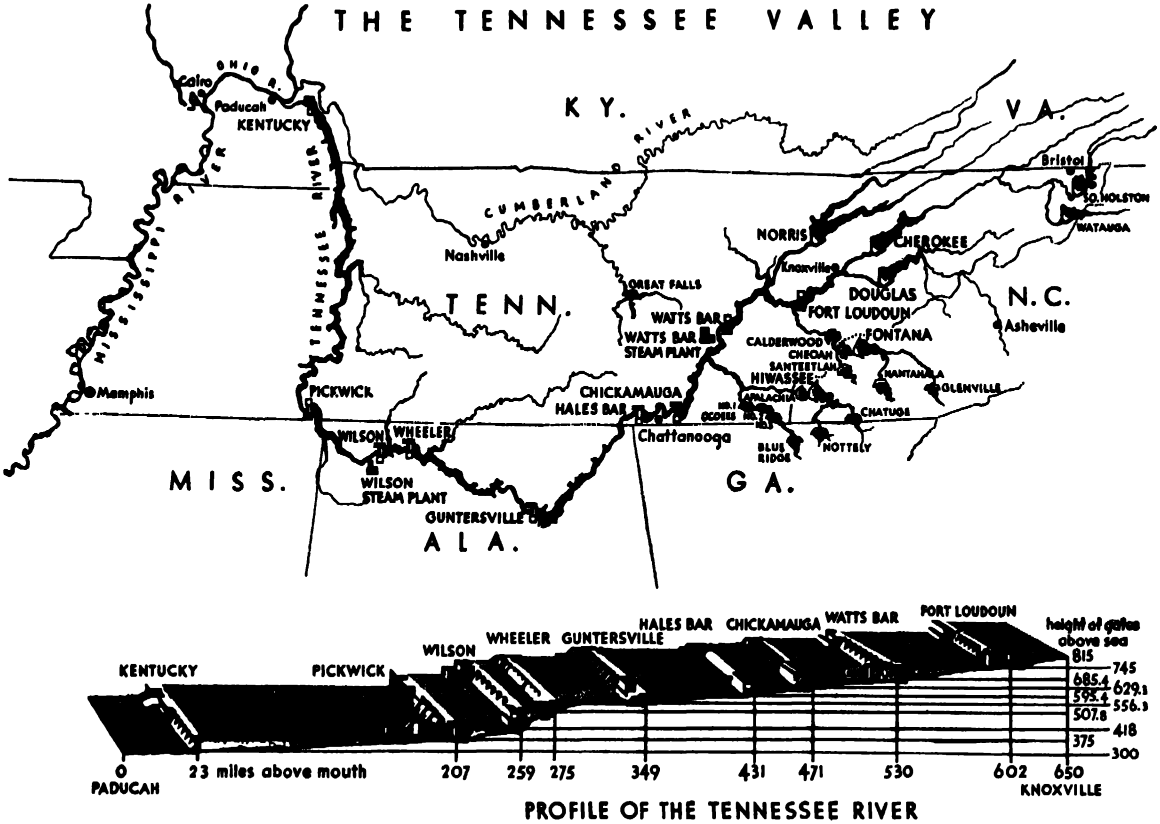


Fig. 309. This map and profile illustrate the steplike continuity of the chain of dams and impounded lakes that harness the Tennessee River and its tributaries. These improvements also serve navigation and flood control. (*Courtesy of Tennessee Valley Authority.*)

This makes feasible the installation of larger power plants and the production of more power. In estimating the power-producing capacity of a site, a stream, or a region it is customary for engineers to state more than one figure. These indicate the quantity of power that could be produced without storage, with complete storage, or on any other practical basis.

566. Land Relief and Potential Water-power Sites. Formerly, usable water-power sites were limited to those available in regions where power was wanted. The power had to be used at the place of its production. The development of hydroelectric power transmission has, to a degree, made the place of power production independent of the place of its use but not entirely. It is not yet economically feasible, in most regions, to send power by wire more than 300 or 400 miles. Moreover, it is not always feasible to use all the possible power of a great stream, even near a power market, because the cost of control and storage works on large streams is high. Therefore, certain power sites of great possibility go unused while others, which are physically less desirable, are developed. Most power sites are chosen because of the benefit of some natural advantage. Such are found in plains regions where a stream crosses an outcrop of resistant rock which increases the stream gradient or causes a narrows, which makes an economical site for a dam.

The disturbed drainageways of glaciated plains, both ice-scoured and ice-deposited, furnish more numerous power sites than are provided on the drainageways of stream-eroded plains. The steep gradients and diversity of rocks found in mountain valleys furnish more frequent and valuable power sites than are common to

plains regions. That is particularly true of recently glaciated mountains. In them snow-fed streams descend through narrow lake-filled valleys of highly irregular gradient or plunge over the steep walls that terminate hanging valleys (Figs. 290 and 291). Although potential water-power sites are numerous in glaciated mountain regions many of them are far from any feasible market for power and cannot now be economically utilized.

567. The World Distribution of Potential Water Powers. Because of the conditions indicated above, the potential water power of the world shows very uneven distribution. In North America the western mountain cordillera has the greatest power possibilities, because of its heavy precipitation, great relief, ice-eroded mountain features, and forested slopes. That region is followed by the Laurentian Shield, which combines with the numerous falls and rapids of its ice-scoured surface a moderate elevation, vast area, a fairly abundant precipitation, and natural water storage in myriad lakes and extensive forests (433, Fig. 201). In Europe the glaciated highland regions of Scandinavia and the Alpine countries hold the largest water-power possibilities. In Asia the conditions are most fully met on the rainy southern front of the Himalayas. In South America there are three significant districts: eastern Brazil, the eastern slopes of the northern and central Andes, and southern Chile. Australia, being generally low and dry, has but little to offer in potential water power. However, Africa exceeds any other continent in this respect. Although much of its area is desert, several great rivers originate in the rainy tropical region, and each of them, on its way to the sea, descends in falls over escarpments from the uplands of this plateau continent (483, Fig. 310).

568. The Value of Streams for Inland Navigation. In nearly all parts of the world, except deserts and mountains, streams are used as avenues of interior transportation. Prior to the development of railways they were used for navigation much more than they are now. Even yet, there are large areas of several continents, including North America, where streams and lakes are the principal highways. Waterways attained early importance as routes of travel because of several advantages that they afforded over primitive land routes. Although they seldom are more direct than land routes, they are, by their nature, reduced to fairly uniform grade and eliminate most of the vertical irregularity common to land routes. Even primitive water craft carry easily burdens too heavy for man or pack animals. On routes from continental interiors outward, heavy loads may be moved on well-graded streams with little expenditure of energy, when aided by the river current.

Certain great rivers offer such advantages for transport, in regions of delayed economic development, that they still carry the major part of the traffic. The Yangtze is the principal means of moving goods to and from the far interior of China. The Congo provides extensive means of carriage in equatorial Africa, although falls cause several interruptions to navigation and prevent direct connection by boat with the coast. The Amazon drains a large area of heavy rainfall over a gradient so low and so free from obstruction as to provide ample depth and width even for any modern craft that are likely to enter there.

However, in the world as a whole, and especially in those countries better provided with roads and railways, river navigation is of decreasing importance. That river transportation has not been able to compete more effectively with that by rail and motor truck is due to important defects in the natural qualities of rivers as water thoroughfares. Some of these defects are indicated in the following statements: (*a*) The depth of most rivers fluctuates greatly with the seasons of maximum and minimum rainfall. This is notably true in arid and semiarid lands where watercourses so seldom are navigable that they never have had significance in that connection, except under special conditions, such as are found in the Nile. Even great rivers, like the Missouri, in regions of seasonal and highly variable rainfall, often are so shallow as to become incapable of use. (*b*) Young streams, which have fairly direct courses, commonly are

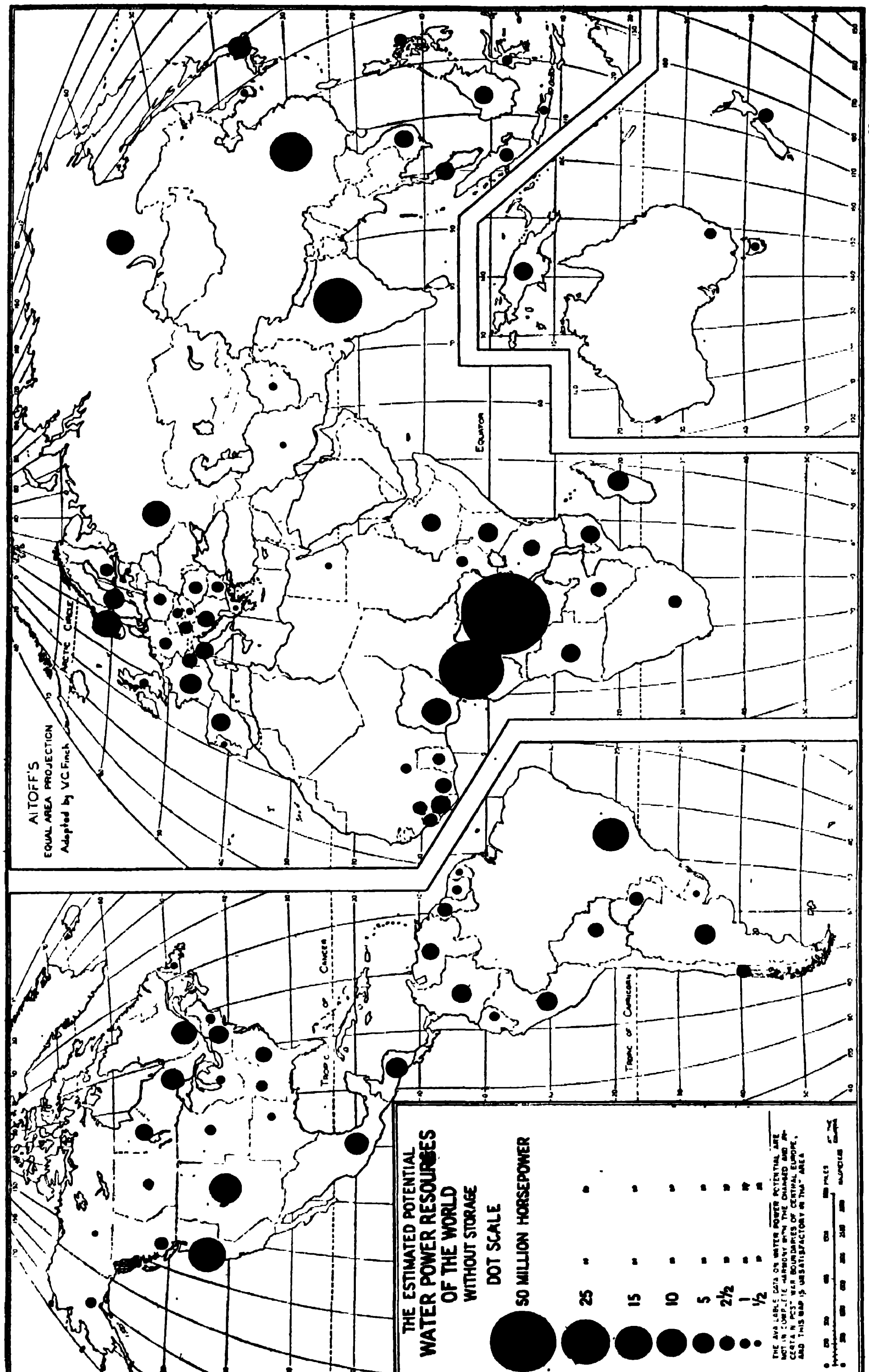


Fig. 310. The areas of the dots indicate the estimated potential water-power resources, without storage, upon a comparative basis. Each dot represents the total figure for the entire area within the boundaries of which it is placed. (*Data from U.S. Department of Commerce.*)

interrupted by falls and rapids, while old streams of low and uniform gradients usually meander and provide long and indirect routes of transport. (*c*) Old streams constantly shift their channels and deposit sand bars which are a menace to navigation. (*d*) In some climates rivers are closed to navigation several months each year by ice. (*e*) It is difficult to provide upon the banks of a river having a variable depth and shifting channel adequate facilities for the transfer of heavy cargo between bank and boat. (*f*) Many places from which goods must be moved are not reached by navigable streams, and other kinds of transport facilities must be provided. (*g*) The movement of river craft is comparatively slow and especially so against the stream current.

569. The Value of Lakes for Inland Navigation. The use of the large lakes or inland seas of the world for navigation presents less difficult problems than does the use of rivers. Some are closed by ice part of the time, but not many are troubled by variable depths or obstructed channels. Owing to their fortunate position between the principal iron-ore and coal regions of the continent, the Great Lakes of North America have been provided with special craft and organized into one of the most effective routes of transportation in the world. They have played a large part in the historical and industrial development of the region in which they lie. Although there is not the same opportunity for special service in other regions, some of the lakes of other continents serve the transportational needs of their regions well. Among the most used of them are the three great lakes Victoria, Tanganyika, and Nyasa in eastern Africa; the Caspian Sea and Lake Baikal in Asia; and others of smaller size.

570. The Value of Lakes and Streams as Centers of Recreation. To most persons a visit to a lake or stream affords a pleasant diversion from the daily routine. The exhilarating sports found in swimming, fishing, and various forms of boating serve as an attraction so strong that large numbers of people make at least a brief annual trip to some body of inland water for purposes of recreation. In recent years the building of good roads and the mobility afforded by the automobile have permitted a widespread gratification of this desire, with the result that large amounts of money are spent by vacationists, and the lakes and streams that attract them have become physical assets of great value to the regions in which they lie.

The greatest number of attractive lakes is found in regions of glaciation. Some of them are the morainic lakes of regions of glacial deposition, but the larger number is found in regions of ice scour or of ice scour with associated morainic damming (433 and 439). It often happens also that the conditions of ice scour which are responsible for the lakes have conspired with climate to render the surrounding land of low agricultural value. This in turn has tended to keep the region in a forested or wild condition, which increases the attractiveness of the lakes and their recreational value. Lake-dotted areas are found in mountain, hill, and plain lands alike. The glacial lakes of the Alpine countries, Rocky Mountain region, high Sierras, or southern Andes add mountain scenery to their attractiveness (535, Fig. 291). The more accessible lakes of the hill lands of New England, the Adirondacks, or the English Lake District and Scotland and the numberless lakes in the plains of the Great Lakes region, eastern Canada, Scandinavia, Finland, or the borders of the Alps draw ever larger numbers of people to their shores. They constitute a resource worthy of studied conservation and development.

CHAPTER 23: *The Biotic Resource: Original Vegetation Cover and Associated Animal Life*

571. Plants Reflect Physical Environment. One of the conspicuous features of the land surfaces of the earth is their plant cover Thus the appearance of an area is, to an unusual degree, affected by the kind and density of its plant cover. Native vegetation is an expression of the composite physical environment. It is the integration of all physical factors, past as well as present, and as a consequence often provides a better basis for classifying and judging the potentialities of environments than any other one single factor or set of factors. The suitability of virgin soil for certain types of land use and crops is often clearly indicated by the vegetation cover. In their broader aspects, the great plant communities which together comprise the earth's mosaic vegetation mantle reflect chiefly *present climatic characteristics*, there being relatively close coincidence between the principal climatic and vegetation types. Modifications within the larger plant communities are usually due to soil, relief, and drainage differences, past changes in environment, fire, or tampering by human beings.

As vegetation develops, the same area may be occupied by a succession of contrasting plant communities. Thus, with the retreat of the continental glaciers in North America and Europe the denuded land surfaces formerly covered by the ice first developed a mantle of lowly plants similar to those of the present tundra. This eventually was replaced by a cover of conifers, which, in turn, gave way to broadleaf and mixed forest in the less severe continental climates. Such an evolution of the vegetation cover is called plant succession. The last stage in such a succession is known as a *climax* or *plant formation*. As the name indicates, each climax or formation is a product of the climate and is controlled by it. The visible unity within the climax is due primarily to the dominants or controlling species. Illustrations of extensive and important climaxes are the tundra of the poleward margins of the Northern Hemisphere continents, the coniferous forest or taiga of the subarctic lands, and the tropical rainforest of the constantly wet lands of the low latitudes.

The classification and brief description of the original vegetation cover here presented is plant geography in its broadest aspects—an attempt to describe the principal plant associations, show their relationships to the environmental complex, and indicate their world distribution (Plate VI). Over considerable parts of the earth, man, through his use of the land, has so greatly modified the original vegetation that at present it bears little resemblance to what it was in its native state.

572. *Animals.* It is nearly impossible to classify animals in terms of environment as one classifies plants. Since the latter are immobile, they must adapt themselves to their environment by their forms and structures. Animals, on the other hand, being mobile, can, within certain limits, change or circumvent their environment, by migrating or burrowing. The plant is a captive of its environment and is compelled to wear the evidences of its captivity in the form of structural adaptations where everyone may see them. Animals, on the other hand, adjust themselves to their physical surroundings by what they *do*, rather than through their structures and forms. As a consequence no attempt is here made to classify animals into

great associations or communities, as is done for plants. Since, however, the type of animal is sometimes closely related to vegetation characteristics, brief comments occasionally are added concerning the representative animal life associated with certain vegetation groups.

Physical Conditions Affecting Plant Life

573. Plant Associations. One does not have to either be a botanist or widely traveled to be aware of the effects of physical environment upon the characteristics and distribution of plants. Even the layman quickly observes that poorly drained locations such as swamps or the periodically inundated margins of rivers and lakes have a distinctive association of plants, which differs markedly from the vegetation cover of higher and drier sites. Certain plants, such as mosses and ferns, are found characteristically in shady, damp locations, while others such as juniper thrive best in sunlight. The above illustrations, to be sure, apply to relatively restricted areas, but in a more general way vegetation cover may have a considerable degree of similarity even over very extensive areas of scores of thousands of square miles, provided the physical environment remains relatively uniform. Moreover, similar environments in widely separated parts of the earth are likely to have plant covers that are much alike in general aspect, even though they are not composed of identical species. Thus the tropical rainforests of the Amazon Basin and the Congo, separated by wide expanses of ocean, are, nevertheless, relatively similar in general appearance and type of plants. So also are the prairie lands of Argentina, the United States, and Hungary.

Based upon common physical needs, therefore, certain plants, although unrelated to one another, are repeatedly found growing side by side in similar environments. It is with these *plant associations* over relatively *extensive areas*, occupying as they do characteristic physical environments, that the geographer is chiefly concerned. These extensive associations comprise the variegated pattern of the earth's vegetation cover. In order to appreciate the significance of the great plant associations and their distribution, some explanation is necessary of the ways in which various elements of the physical environment influence vegetation.

574. Temperature and Light. Unlike many animals, plants do not generate heat. As a consequence their very existence as well as their characteristics are greatly influenced by the temperatures of air and soil. For every species of plant there appear to be three critical temperatures: (*a*) lower, and (*b*) upper limits beyond which it cannot exist, and (*c*) an optimum temperature in which it grows most vigorously. The lower limit is sometimes called its *specific zero.* This minimum temperature is not necessarily associated with 32°, for many tropical plants perish before the freezing point is reached, while certain forms of Arctic vegetation thrive in subfreezing temperatures.

Different species resist cold in different ways. Some make the adjustment by retarding growth and arresting certain functions, such as assimilation and respiration, during the period of low temperatures. This may result in a marked external change such as takes place with leaf fall in middle-latitude deciduous trees. Certain other plants, such as coniferous trees or the evergreen shrubs of Mediterranean climates, lapse into a dormant period without any apparent outward change. In some species the plant completes its entire life cycle during the warm period, so that the vegetative portions disappear entirely throughout the season of cold and it is only by means of a seed, which is capable of greater and more prolonged resistance to low temperatures, that the plant is perpetuated. These are the *annuals,* of which, for instance, rice and corn are representative. They stand in contrast to *perennials,* the vegetative parts of which live on year after year.

The length of the vegetative period is not alike for the same plant in contrasting climates. In regions of short summers, such as Siberia, the growth period is reduced to 3 or 4 months, but at the same time the rapidity of growth during the shortened summer is great. For example, the beech, which completes its seasonal growth

in 3 months in the latitude of Yakutsk, Siberia, requires 6 months in central Germany.

Not only heat but also light affects the characteristic development of plants. Reproductive functions, for instance, are favored by light. This is shown by the fact that flowers can be prevented from opening by being grown in semidarkness. Those plants which grow in shade usually are characterized by greater development of their vegetative parts, such as stems and leaves, at the expense of flowers which contain the reproductive organs. On the other hand, light tends to produce large, brightly colored flowers but thicker and shorter leaves and stems.

575. Water. (Hygrophytes, Xerophytes, and Tropophytes.) No plants can live entirely without water. Taken in at the roots it is the principal ingredient of sap, in which mineral matter in solution is carried to all parts of the plant. Transpiration of water takes place through the leaves, the process being associated with chemical changes by which the sap is prepared for assimilation by tissues.

Plants that exist in water or in very damp and humid regions are designated as *hygrophytes*. In these the stems are usually long and relatively fragile, containing a minimum of woody fiber, while leaves are large and usually thin. Roots are likely to be shallow. The banana tree, characteristic of the wet tropics, is an example of hygrophytes. At the opposite extreme are the *xerophytes*, which are adapted to drought conditions. In these, roots are long or widespread in order to increase the depth or area from which water is obtained, while stems are likely to be shorter and stronger. Leaves are smaller and thicker, their stomata (openings for transpiration) fewer, and a hairy undercover is common. A thick corky bark or a coating of wax may further protect against rapid transpiration. Leaves even may be replaced by thorns. Certain desert species adapt themselves in a different way, *viz.*, by accumulating supplies of water within their vegetative structures. Such a one is the fleshy-stemmed cactus.

In climates that have a wet and a dry period, or in those in which there is a distinct period of cold, many plants are hygrophytic in one season and xerophytic in the other. These are called *tropophytes*. In savanna climates, for instance, most trees drop their leaves during the period of drought and temporarily become xerophytes, for the woody stems and branches and the shiny wax-covered buds are highly conservative of water. With the coming of the rains again the buds open, and hygrophytic leaves and reproductive organs are formed. In middle latitudes the season of cold has a similar effect to that of the season of drought in the tropics, for the rise of sap is checked by low temperature as well as by low rainfall. Thus winter is a period of physiological drought during which deciduous plants lose their leaves and become xerophytic in character.

576. Soil. Although temperature and water are the two principal physical elements determining the general character of the earth's natural vegetation, modifications within the great climatically induced groups are due principally to soil contrasts (the *edaphic* factor). Thus within the northeastern pine forests of the upper Great Lakes states, the composition of the original stand depended largely on the character of the soil. On the poorest sandy soils jack pine was almost the exclusive tree. On the somewhat better sandy soils Norway pine was intermingled with jack pine; while in regions of higher fertility Norway pine occurred in mixtures with white pine and northern hardwoods. Throughout the hardwood forests of New York white pine occupied the sandy plains. In its modifying effects upon plant life the soil environment makes itself felt in a number of ways, especially through its temperature, chemical composition, and water retentiveness. Sandy or stony soils, which are very porous, may induce a xerophytic vegetation even in regions of moderate rainfall. Thin soils are likewise inclined to be droughty. Where a high percentage of salt is present, as in parts of deserts or along seacoasts, most plants will not grow. Vegetation in such areas of salt concentration has distinctive characteristics, being xerophytic in many respects. A proportion of over 3 per cent of lime in soil is likewise injurious to most vegetation. In cool, damp, subarctic regions, the barren

soils of which are covered with raw and highly acid humus, such xerophytic plants as heather and furze are characteristic.

The Great Plant Associations

577. Three Principal Classes of Vegetation. Plant geographers recognize three principal classes of natural vegetation: (*a*) forests, (*b*) grasslands, and (*c*) desert shrub, including tundra. Each of these occupies contrasting types of environment, rainfall probably being the single most critical element leading to the threefold differentiation. As listed above, the three vegetation groups are arranged in order of diminishing rainfall, forest occupying the regions of wettest climate and desert shrub the driest, while grasses are intermediate in their requirements.

578. Woodland or Forest Associations. Within this group the tree is the essential element. Other woody plants such as bushes and shrubs, together with grasses and parasitic forms, may be present as well, but these are usually only accessory parts of the forest. When trees grow in a closed formation and are so close together that their crowns touch, the result is a genuine *forest*. If shrubs are so numerous that they prevent the tree crowns from touching, *bushwood* is the common name, while a predominance of shrubs leads to the designation *shrubwood*. Woodland associations dispute the possession of the land with grassland associations, forests in general occupying the more rainy parts of the world and becoming increasingly luxuriant with increasing temperatures.

579. *Forest Climate.* It is not unusual that forests should be more water-demanding than the other great vegetation types. (*a*) In general the tree has a larger transpiring surface, compared with the area of ground covered, than have other plants; (*b*) its transpiring surface is farther away from the water supply in the soil; and (*c*) by reason of its height it is more exposed to wind and evaporation. On the other hand, because of its deep and extensive root system the tree is able to tap deep-lying supplies of water and is capable of withstanding drought during the vegetative or warm season (which grass cannot), provided there is a continuous supply of water at the roots. In other words the *season of rainfall* is of less significance to trees.

The limiting factors in forest growth may be summarized as follows: (*a*) Low temperatures limit forest range both in high latitudes and in high altitudes. Since a large amount of permanent plant tissue is required to form a tree, and moreover, since the new shoots formed each season have to be matured sufficiently to be able to endure the following drought or cold period, it follows that forests require a fairly long growing period. Even the hardiest conifers require a mean warm-month temperature of not less than 50°F. The isotherm of 50° for the warmest month, therefore, approximately marks the poleward limit of forests. (*b*) The subsoils must be permanently moist, and the moisture must be present in a form that is readily available. Climates with highly variable rainfall are not well suited to forests for there is danger of exhaustion of soil-moisture reserves. Demands upon soil moisture are greatest in the growing season so that, other things being equal, a climate with a warm-season rainfall maximum is more favorable for forest growth than one where summers are dry and winters wet. Since a tree absorbs some moisture even in the dormant period, a climate whose rainfall is excessively seasonal in character tends to inhibit tree growth. (*c*) In climates with very low winter temperatures, the prevalence of strong or continuous wind is injurious to trees. Wind is directly related to the rate of transpiration, and strong dry winds during the cold season when the soil moisture is locked up through freezing are particularly bad. Thus winds are a limiting factor to forest growth both in high altitudes and high latitudes. A good forest climate, therefore, is one with a warm rainy vegetative season, a continuously moist subsoil and a low wind velocity, especially in the dormant season.

From what has been said above it is now possible to outline the general world pattern of forest distribution as would appear on a hypothetical continent of relatively low and uniform elevation (Fig. 311). Forests are excluded from the

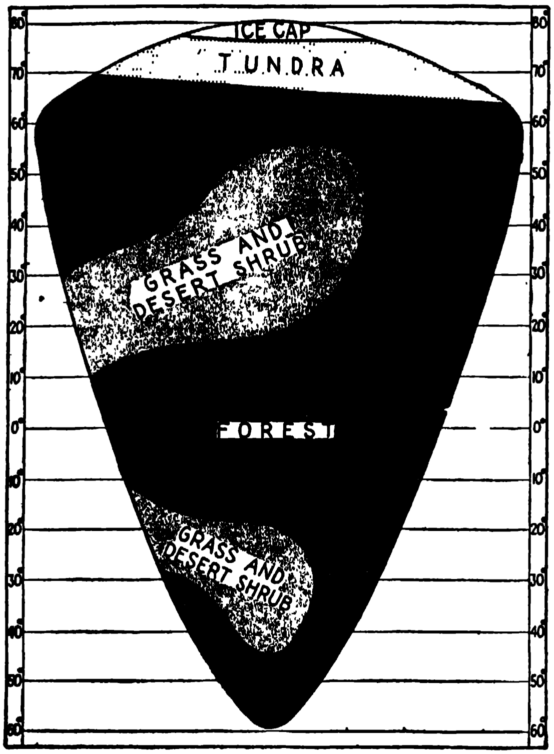


Fig. 311. A highly generalized distribution of the principal vegetation types on a hypothetical continent.

high latitudes, poleward of the 50° isotherm for the warmest month, by the absence of a period of sufficient warmth and by the cold dry winds of winter. In the middle latitudes they occupy both the eastern and western portions of the continent, but are excluded from the deep interiors because of the prevailingly dry climates in those locations. Within the tropical latitudes forests prevail in the rainy portions extending out 10–15° either side of the equator and even farther on the eastern or windward sides. Poleward from about latitude 15° in the interior and western or leeward sides of the continent, drought tends to exclude forests (Fig. 312).

580. Grassland Associations. The vegetation cover here consists principally of perennial grasses, although other herbaceous plants may be present in considerable numbers. In the low latitudes grasslands often are called *savannas;* in the middle latitudes they go by the names of *prairies* (tall grass) and *steppes* (short grass). The term steppe is gradually coming to be applied to all the drier short-grass grasslands, tropical as well as middle latitude. Grasslands in wet or poorly drained areas are designated as *meadows.*

581. *Grass Climate.*[1] Natural grasslands probably exist in those parts of the earth where climatic conditions are unsuited to the growth of trees without at the same time being sufficiently harsh so as to induce the development of desert plant communities. Usually it is neither climatic nor soil factors which discourage the growth of grasses, but rather the competition of trees. In part this may be due to the shade produced by the forest canopy; even more it results from the starvation of the grasses in terms of water and nutritive salts by the greedy tree roots. Thus, while there are relatively few forest areas where because of climatic and soil conditions grasses cannot thrive, the converse of this statement is not true. Although meadow thrives in cool moist locations, most natural grasslands are either subhumid or semiarid. Since most grasses are relatively shallow rooted, they suffer from prolonged drought *if it coincides with the warm period or growing season.* Climates with winter rains and summer drought, therefore, are not ideal for grasses. Moisture in the deep subsoil is of little value; it is the surficial layers that are critical. Since this top moisture is quickly lost by evaporation, frequent, even if weak, precipitation is essential during the growing season. During the resting period (winter in middle latitudes) grasses can endure great drought without injury. Winds are of little significance, since grass does not grow tall enough to be greatly affected by any but the slower-moving ground currents. Most hostile to grass is drought during the growing season. It is

[1] Some have expressed the idea that grasslands, at least those in the tropics and subtropics, are not the result of climatic conditions. Rather, they would attribute them to the work of man, believing that grasses become established as a result of burnings and clearings of the forest in carrying on agricultural operations. Their notion would be that a distinctive grassland climate does not exist, since they maintain that woody vegetation can invade any region where rainfall is sufficient for grasses. See O. F. Cook, Milpa Agriculture, a Primitive Tropical System. *Smithsonian Inst. Ann. Rept.,* 1919, pp. 307–326.

a common sight in middle latitudes during dry summers to see pastures and lawns brown and sear, while the trees and bushes are as verdant as usual. Grass, then, is typical of subhumid and semiarid regions which have a marked concentration of the year's rainfall during the warm season (Fig. 311).

582. Desert Shrub. As far as plant life is concerned, deserts are of two types: (*a*) those which are *physically* dry, with little water present in any form, and (*b*) those which are *physiologically* dry. In the latter, although water may be adequate, it exists in inaccessible forms, usually snow or ice. Sahara is representative of the first type, and the polar regions of the second. In both, however, lowly, widely spaced, xerophytic plants predominate. Neither trees nor grasses thrive, and stunted forms of either woody or herbaceous plants capable of enduring the adverse climate prevail (Fig. 312).

Rarely are there sharp boundaries separating woodland, grassland, and desert, but almost always gradual transitions from one to the other. As a consequence there are wide transitional

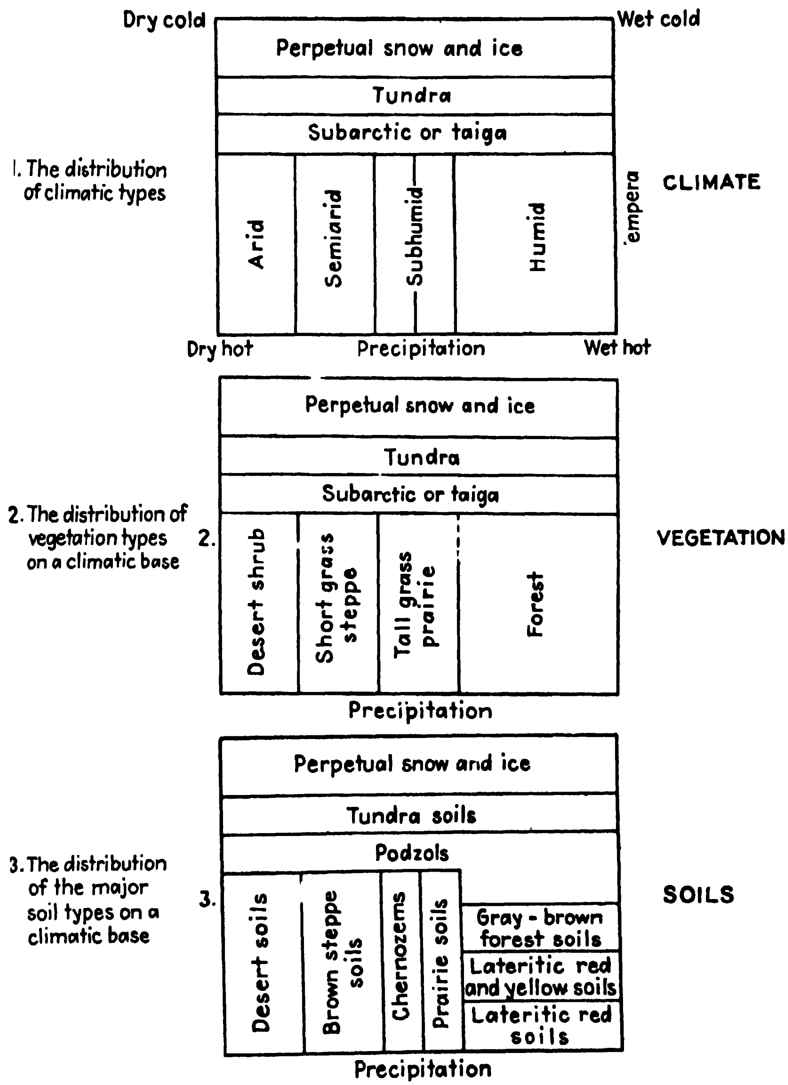


Fig. 312. Schematic representation of the distribution of native vegetation and soils in relation to climate. (*After Thornthwaite and Blumenstock.*)

Fig. 313. Tropical rainforest in the Amazon Basin. (*Hamilton Rice Expedition of 1924–1925.*)

belts between grasslands and forests known as wooded steppe, or park savanna, where trees and grass intermingle. Similarly, transition belts occur between forest and desert and between grassland and desert.

Types of Forests and Their Distribution[1]

LOW-LATITUDE FORESTS

583. Tropical Rainforest. This most luxuriant type of woodland community characteristically occupies warm tropical lowlands where rainfall is heavy and well distributed throughout the year, there being no marked dry season. The Amazon Basin in Northern South America and West Central Africa are the two largest areas of tropical rainforest, although it is found along many rainy coasts and islands in the tropics as well (Plate VI). Three principal characteristics feature this forest type: (*a*) There is a great variety of different species of trees present. This is in contrast to most middle-latitude forests, where one, or at most a few, species, such as pine, hemlock, oak, or maple, may form almost solid stands. (*b*) There is developed to an unusual degree a vertical stratification in the forest, this feature arising from the fact that the multiple species arrange themselves in several groups, each having a particular height limit. The result is a forest with a number of tree tiers, each with its own height level and each lower one reflecting an increasing tolerance for shade as imposed by the canopy above. (*c*) The number of climbers, lianas, and epiphytes is unusually large. The giant lianas have the appearance of great cables interlacing the branches of the forest crown and binding the individual trees together.

584. *External Aspect.* Luxuriant, complex, exuberant—such is the character of tropical

[1] Trees are classified as either (*a*) broadleaf or (*b*) needle leaf (conifers); (*a*) deciduous or (*b*) evergreen. Evergreens are those which retain some foliage throughout the year, while deciduous trees periodically lose their leaves and are therefore bare for a portion of the year. Broadleaf trees are both evergreen and deciduous, although the conifers are rarely deciduous.

rainforest (Fig. 313). In external aspect it presents a richly varied mosaic of many shades; gray, olive, brown, and yellow tints being more common than the fresh green of middle-latitude woodlands. The skyline, too, is different, the crown of the tropical forest being irregular and jagged with many crests and furrows. This comes from the great variety of trees of varying heights which comprise it. No other forest equals it in richness of species, and these are intricately intermingled. Pure stands of a species are practically unknown. Tropical rainforest is evergreen broadleaf in character, there being no general dormant period when the forest as a whole is bare and without foliage. On the other hand, the leaves are, as a rule, renewed each year, but different species drop their leaves at different times. For the whole forest leaf shedding is a sporadic thing rather than seasonal for all the species. Individual trees without leaves may be observed at any time in the rainforest, but the new crop is not long in appearing. (Fig. 314). Just as the climate is without a marked seasonal rhythm, the vegetation is likewise. Needle trees are largely absent, leaves characteristically being broad and thin.

585. *Internal Aspect.* An internal view shows the tropical rainforest to be composed of tall trees (often 150 ft. high) with large diameters, growing close together. The result of its being a multistoried forest is a dense canopy of shade with very subdued light underneath (Fig. 314). In the Congo forest Shantz found that the time required for a photograph was twenty thousand times the normal exposure in the open. The trees have few lower branches, their trunks characteristically being smooth, resembling a conifer more than an oak. Lianas, climbing plants, epiphytes, and parasites are relatively abundant.[1] This mass of vines and creepers appears almost to suffocate the trees that are its supports. Within the forest the tall, branchless trunks resemble gigantic dark columns supporting an almost impenetrable canopy, composed of the interlocking crowns of the trees and the vines and creepers that cover them. In the virgin forest, because of deep shade, undergrowth is not unusually dense although often sufficient to obstruct distant views. In regions of deepest shade only a thick mat of herbs or ferns covers the floor, so that one can proceed in all directions without following paths or even chopping new ones. Typical *jungle* conditions, with a thick and impenetrable undergrowth, chiefly are characteristic of sections where light reaches the forest floor, for example, along rivers and coasts, on precipitous wet slopes, and in abandoned agricultural clearings (Fig. 315). Reflecting the abundant moisture in the surface soil, tropical rainforest trees are relatively shallow rooted and consequently weak in holding power. Their great trunks commonly are supported by giant buttress roots, in the form of

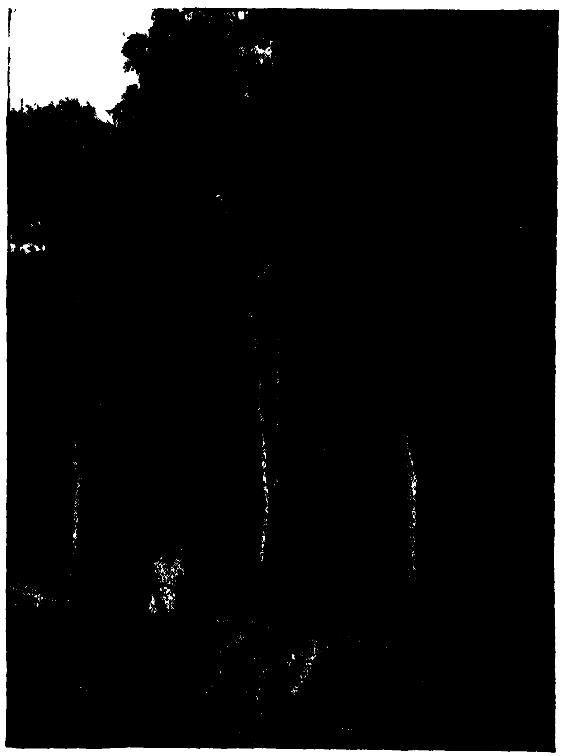


Fig. 314. Side view of tropical rainforest in Brazil. Note the abundance of lianas and the dense forest crown. (*Field Museum of Natural History.*)

[1] *Lianas* are ropelike plants which entwine themselves round trunks and branches. *Epiphytes*, of which orchids are a common example, characteristically grow on the branches of tropical trees and spread their roots among the cracks in the bark. They frequently have hanging roots. *Parasites* are plants that feed from the sap of the tree on which they grow.

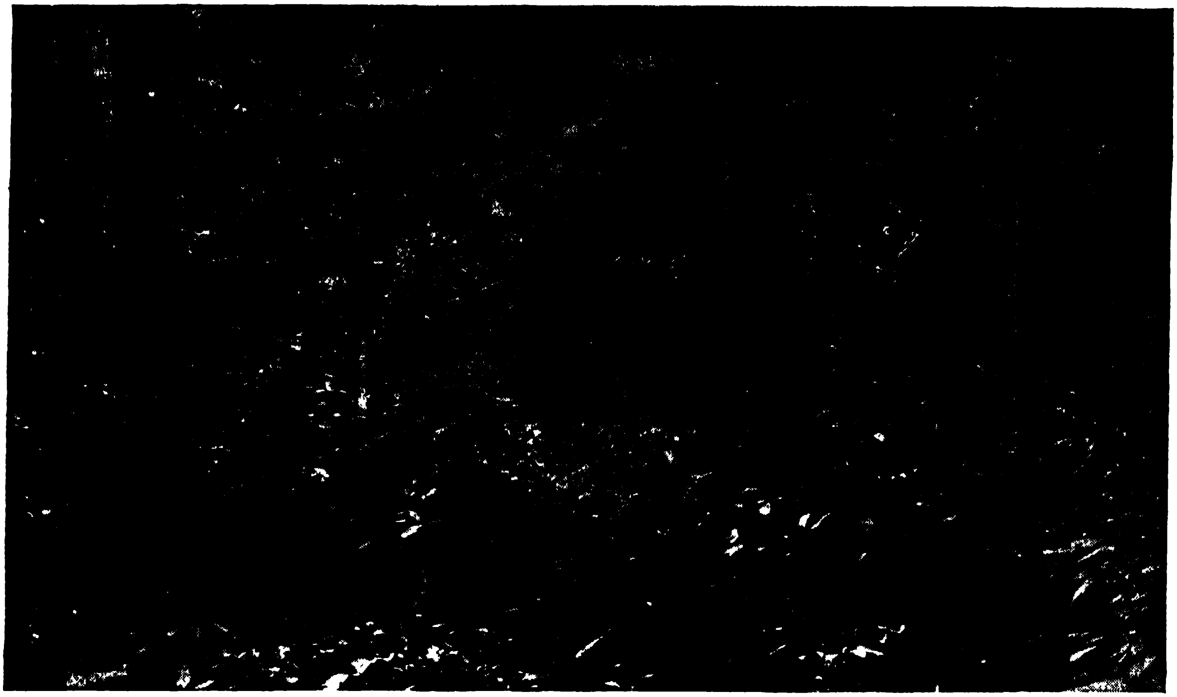


Fig. 315. Interior view of the tropical rainforest in the Belgian Congo. Time required for this photograph was 20,000 times the normal exposure in the open. Undergrowth appears to be more dense than in Fig. 314. (*American Geographical Society.*)

winglike outgrowths which extend 10 to 25 ft. up the stems.

Of the Amazon forest, Haviland writes:

> If the approach is by boat up one of the great rivers, which are still the only highways through the greater part of the forest region, the sight is one of unforgettable grandeur. On either side the banks are veiled by a wall of green foliage between 100 and 200 ft. high, towering above its own inverted image in the water. . . . This profusion of flowering climbers, which in some places hides the outlines of the trees themselves, is characteristic of the South American forest. The creepers cover the whole roof of the forest as with a canopy and fall to its foot at the water side like a curtain. . . . This mass of creepers is not altogether the suffocating burden or host of parasites that it appears to be. In exchange for support, it affords shade which is essential to the well-being of the forest; and it has been shown that when the veil has been torn aside so that the sun can beat down on the roots, the giant trees perish. For this reason an artificial clearing is usually fringed with dead trees.
>
> Here and there dark caverns yawn in the wall of foliage at the water side. These are the mouths of creeks and streams shut in by overarching branches from which long aerial roots hang down like stalactites. To enter these caves by boat is like passing from the open air into a vast dim hall, supported by immense columns. The trunks of the trees rise up for 70 or 80 ft. without a branch, and the undergrowth is thin and straggling. The ground is strewn with dead leaves, though it may be remarked that the accumulation of leaf mold is not very great, owing to the rapidity of bacterial action.[1]

586. *Animal life* of the tropical rainforest is not so conspicuous as is the vegetation, although it varies in kind and abundance from one region to another. In the crown of the forest, where there is an abundance of food, a great variety of birds and some climbing animals such as monkeys and apes exist. On the darkened floor below, large animals usually are not numerous, although in Africa the hippopotamus inhabits the river margins, and elephants, giraffe, and the big catlike animals may penetrate the forest for some distance. Reptiles and amphibians are

[1] Maud D. Haviland. "Forest, Steppe and Tundra." Pp. 42–43. Cambridge University Press, London, 1926.

relatively abundant. It is chiefly in insect life, however, that the tropical forest abounds. Although not conspicuous, and very elusive, the hum and sing of insect life are ever present. Ants are among the most numerous forms, and termites, a kind of destructive woodworm, are likewise abundant. Not only in the tropical forest, although there some of the most ideal conditions exist, but throughout most poorly drained areas in the low latitudes are to be found parasitic disease-carrying insects, some of them dangerous alike to man and animals. Yellow fever, sleeping sickness, and malaria, veritable scourges of the tropics, are all of them propagated through the bites of insects.

587. *Rainforest Subtypes.* Several subtypes of the general tropical rainforest are recognized. Thus along tropical salt-water coasts are the *mangrove swamp forests*, which find ideal conditions in waterlogged brackish marine mud. They are most extensive in the vicinity of river mouths. Standing upon prop roots which lift the main trunk of the tree above high tide, the mangrove forest at low water presents an impenetrable tangle of roots and knees covered with algae. Occupying river floodplains and other low periodically flooded places are the *intermittently inundated forests*. Probably owing to the frequent floodings, climbing plants and lianas are less abundant than in the drier forests, while the tree types, too, are somewhat different. The *higher lying forest* appears to have a denser undergrowth, but it probably varies considerably from place to place in penetrability. The tree trunks, as well as the crowns, are usually burdened with a host of climbing vines, woody lianas, or "monkey cables," and parasitic plants. Many tropical forests do not represent truly virgin growth, but various stages of natural reforestation following burnings and clearings by the native inhabitants.

588. Lighter Tropical Forest (Semideciduous). This forest has temperature requirements similar to those of the tropical rainforest but, in contrast with it, occupies either regions of less rainfall or, more typically, those where there is a distinct, but short, dry period which imposes a partial seasonal rhythm (Plate VI). Relatively

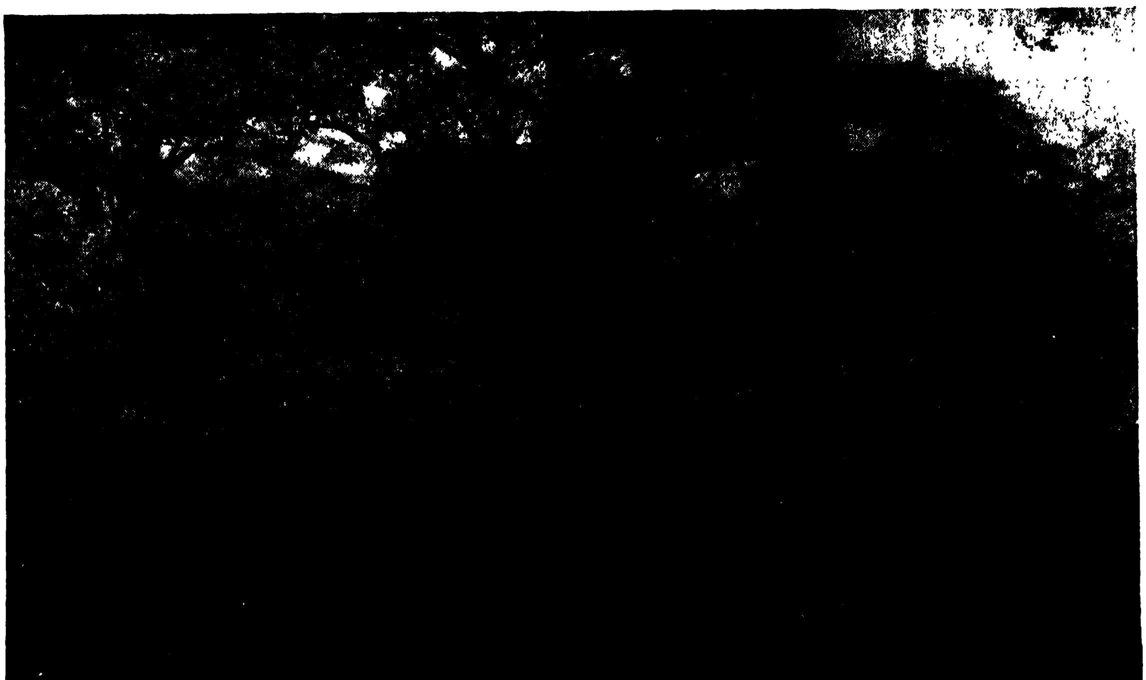


Fig. 316. Lighter tropical forest (semideciduous) in the Belgian Congo. Large trees are sufficiently far apart not to cast a dense shade. Grass mantles the forest floor. (*American Geographical Society.*)

large areas of this type of forest exist in monsoonal southeastern Asia. There it often is designated as *monsoon forest*. A somewhat similar type, the *savanna forest*, occupies transitional belts between tropical rainforest and the drier park savanna or grass savanna (Fig. 316). But these latter areas are not always sufficiently distinct, or their situations well enough known, to permit of localizing them on a generalized vegetation map of the world. Characteristically the lighter tropical forest is broadleaf deciduous in character, although not all the trees are leafless during the dry season. It is during the period of drought, nevertheless, that contrast with the rainforest is most marked. Further features of differentiation are the wider spacing of the trees, their somewhat smaller size, and the denser undergrowth which occupies the less-shaded forest floor. Tall bamboo thickets are common in the monsoon forests, while high coarse grasses prevail in some other regions (Fig. 316). Climbing vines and epiphytes may be numerous.

589. Scrub and thorn forest varies in density from an open parklike growth of low stunted trees and thorny plants to dense thickets of the same (Fig. 317). Where grasses mantle the forest floor they are not dense but consist of tall forms comprising a rather open cover. The trees composing the dry scrub forest are small in diameter, rarely exceeding one foot. Normally they are deciduous in character, bearing their foliage and flowers only during the period of rains. Scrub forest commonly occurs in scattered small areas throughout savanna lands where soil conditions are unfavorable for growth of grasses. It is likewise adapted to areas of relatively low rainfall where the precipitation is irregular and undependable and interrupted by dry periods. No other tropical forest type equals it in tolerance of physical conditions.

Fig. 317. Scrub forest in Senegal, West Africa. (*Field Museum of Natural History.*)

Utilization of Tropical Forests. Although tropical forests occupy nearly 50 per cent of the earth's total forest area, at the present time they supply only the limited needs of local populations and furnish to world commerce small quantities of special-quality woods, such as dyewoods and cabinet woods. Nevertheless these low-latitude forests, especially the tropical rainforest, represent one of the world's great potential timber supplies. The problems involved in their utilization are serious—labor supply, sanitation, requirement of new logging technologies, how to utilize the great variety of species composing the tropical forest—but none of them appears to be insurmountable.

MIDDLE-LATITUDE FORESTS

590. Mediterranean Broadleaf Evergreen Scrub Forest. Mediterranean forests are a relatively rare type, for seldom are trees broadleaf evergreen and at the same time adapted to regions with long, hot periods of summer drought. In those parts of the humid tropics where pronounced dry seasons are characteristic, trees protect themselves by shedding their leaves and thereby becoming xerophytic during the dry season, although they are hygrophytic during the periods of rains. In Mediterranean woodlands, on the other hand, adjustment is made in other ways, protective devices against rapid transpiration permitting the trees to retain their foliage, and consequently their evergreen characteristics, during the period of aridity. But although evergreen in character, there is more of a seasonal rhythm in vegetative and reproductive processes than is true of the tropical rainforest. This unique Mediterranean woodland is found in subtropical regions with mild, rainy winters and long, dry, hot summers. The climate as well as the vegetation is unusual, for the times of maximum temperature and

Fig. 318. Mediterranean sclerophyll woodland in California. An open stand of dwarf oak merging with grassland. (*U.S. Forest Service.*)

maximum rainfall do not coincide. The largest representative area is the Mediterranean Sea borderlands, with smaller areas in California, middle Chile, southern Australia, and the Cape Town region of Africa.

Mediterranean woodland is predominantly a mixed forest of low, or even stunted, trees and woody shrubs (Fig. 318). Tall trees are rare. Where climatic and soil conditions are most favorable the virgin forest is composed of low, widely spaced trees with massive trunks and gnarled branches. Between the trees the ground is completely or partially covered by a pale, dusty, bush vegetation, which very much resembles the soil in color. From a distance, therefore, it may appear as though the ground were almost bare of small plants. In all of them woody parts are more prominent than foliage. As a protection against evaporation the tree trunks are encased in a thick, deeply fissured bark this feature being perfectly exemplified by the cork oak. Leaves, too, which are small, stiff, thick, and leathery, with hard, shiny surfaces, are designed to prevent rapid losses of water.[1] The olive tree with its massive trunk, gnarled branches, thick fissured bark, and small, stiff, leathery leaves is very representative of Mediterranean sclerophyll woodland in regions of hot (*Csa*) summers.

Even more common than the woodland composed of low trees and shrubs described above is a vegetation mantle consisting principally of shrubs and bushes in which there may be some stunted trees (Fig. 319). This bush thicket is known as *chaparral* in California and *maqui* in lands bordering the Mediterranean Basin. In places the woody shrubs form a thick and relatively tall cover; in others it is short and

[1] It is this leaf characteristic which has given the Mediterranean woodland the name *sclerophyll*.

sparse. Chaparral in some regions may represent the original vegetation cover. In other sections it is the underwood remaining after the low trees of the original woodland have been destroyed. The chief economic importance of chaparral usually lies in its watershed protection.

591. Broadleaf Forests. Within the more humid parts of the middle latitudes are found two great forest groups: (*a*) the broadleaf trees, and (*b*) the needle-leaf conifers. Over large areas they exist as mixed conifer-broadleaf forests. As a general rule, but with important exceptions, the coniferous forests occupy the colder continental locations and so are usually on the poleward side of the broadleaves. In regions of poor, sandy soils, such as the Atlantic and Gulf Coastal Plain of the United States, or on steep mountain slopes where soils are thin or rocky and temperatures lower, conifers may supplant broadleaves even in the lower middle latitudes. The latter condition is illustrated in the case of the southern Appalachians, which carry a long tongue of coniferous and mixed forest southward into the broadleaf belt.

Temperate broadleaf forests vary widely in composition, the dominant tree species differing from one region to another. In parts, especially along their poleward margins, there are numerous conifers among them, so many, in fact, that some plant geographers designate such forests as *mixed* rather than broadleaf (Figs. 320 and 321). In eastern United States two general broadleaf-forest areas are distinguished: (*a*) a northeastern one (northern Wisconsin and Michigan, New York, and southern New England) in which birch, beech, and maple predominate but with a large infusion of hemlock and other conifers; and (*b*) a central and southern one lying south of the first and terminating at the northern and western boundary of the sandy Coastal Plain (Figs. 322 and 323). In this latter forest, which was originally the finest and most extensive area of broadleaves anywhere in the world, oak, chestnut, hickory, and poplar predominate but with pines prominent toward the Coastal Plain margins. The greater part of the original American broadleaf-forest belt, lying as it does in an environment

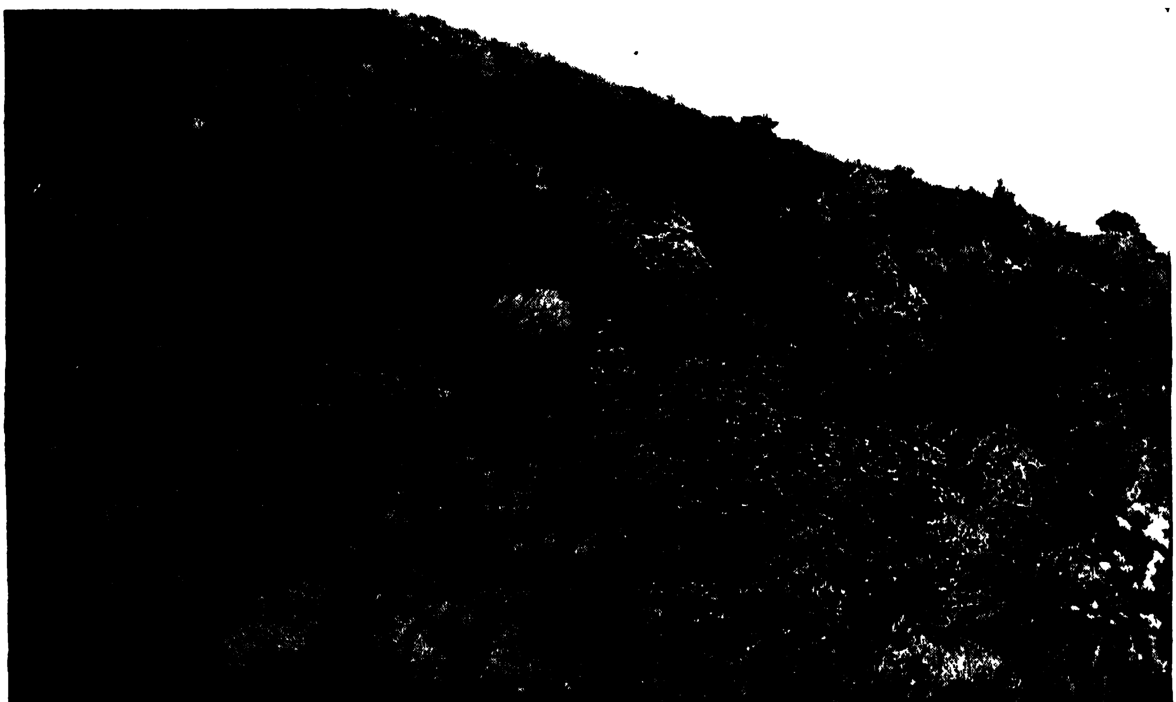


Fig. 319. Mediterranean chaparral or maqui in Cape of Good Hope Province, South Africa. (*American Geographical Society.*)

eminently suited for agriculture, has now been cleared and turned into farmland. Poorer cutover lands often have a brush cover. Of the 280,000,000 acres comprising the original central broadleaf forest only 14,000,000 acres of virgin forest remain and the timber cut exceeds the timber growth by a considerable margin. The remaining stands are chiefly in the rougher Appalachian country and in Tennessee, Kentucky, Missouri, and Arkansas. Outside the United States, other relatively large areas of temperate broadleaf or mixed forest are to be found in Japan, Korea, southeastern China, central Russia, Rumania, southwestern Siberia, western Europe, southern Chile, southeastern Australia, and New Zealand (Plate VI).

592. *Deciduous Broadleaves.* By far the greater part of the temperate broadleaf forest is *deciduous* in character, the trees dropping their leaves during the winter season (Fig. 321). Except in the dormant season this forest is rather uniformly bright green in color, and its profile is regular. The amount of underwood varies with density of tree stand, being much greater where an appreciable amount of light reaches the ground. Trunks of the deciduous trees are xerophytic in character, having a relatively thick bark which protects against transpiration during winter. On the other hand, the leaves are thin and delicate, requiring no protective devices, since they remain on the tree only during the warmer part of the year. As a result of seasonal leaf fall, for the year as a whole, considerable sunlight reaches the soil under deciduous forests.

593. *Evergreen Broadleaves.* Only along the humid subtropical margins of the middle latitudes are there important *evergreen* broadleaf forests, but these are not nearly so extensive as the deciduous variety. Their principal regions are in southern Japan, New Zealand, and southeastern Australia. In many respects these subtropical forests are akin to those of the wet tropics. Lack of seasonal leaf fall, density of undergrowth, and prevalence of lianas and other climbing plants, all are suggestive of the resemblance. The number of species composing the forest is likewise considerable. Oaks of various kinds are among the commonest trees. Eucalyptus and acacia are important elements of the Southern Hemisphere forests.

Fig. 320. Mixed broadleaf-conifer forest (birch-beech-maple-hemlock) in Michigan. Much of the land formerly occupied by this forest type is not well suited to agriculture. It is the relatively barren, cutover land of the Lakes States. (*U.S. Forest Service.*)

594. Coniferous Forests. Coniferous trees are almost exclusively *evergreen*, the addition and fall of the needles being a continuous process and not confined to any particular period or season. In some species the leaves may remain on the trees for 5 years or more. Unlike broadleaves, however, the needles of conifers are xerophytic in character so that shedding is not necessary to protect against a cold or drought season. On the whole, the crown of a coniferous forest does not intercept so much sunlight as does that of the broadleaf woodland, but (*a*) since the former lie predominantly in higher latitudes where there are longer periods of low sun, and (*b*) since they are never without foliage, less sun reaches the earth. As

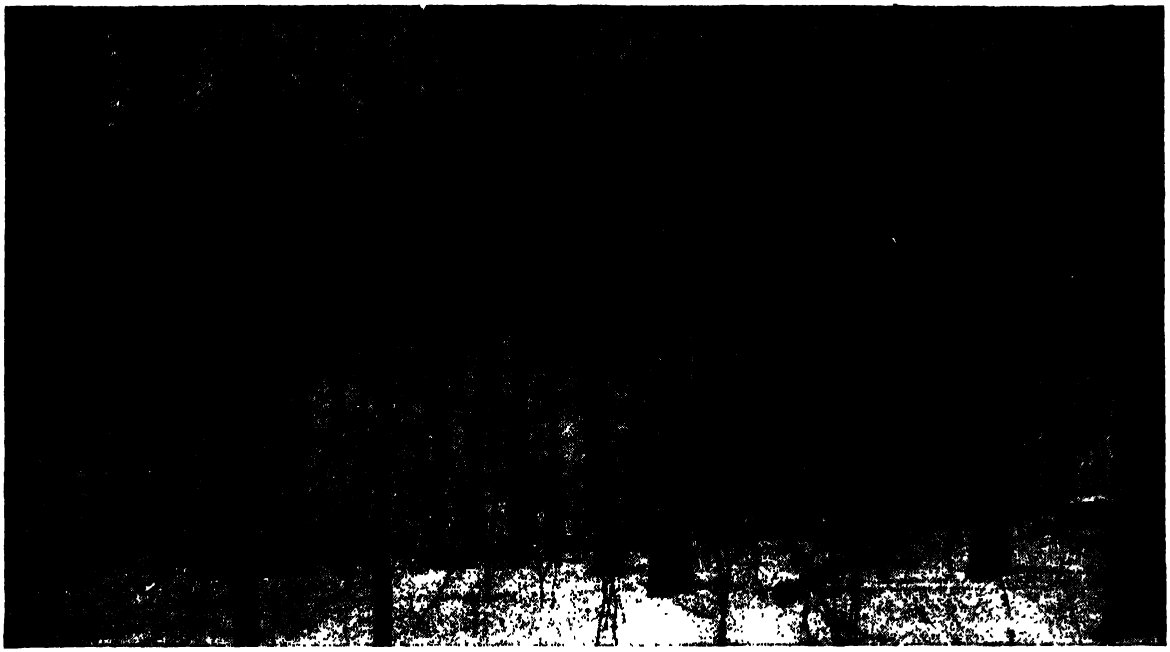


Fig. 321. A mixed broadleaf-deciduous forest (oak-hickory) in northern Indiana. Much of this type of forest occupied good agricultural land and as a consequence, was destroyed in the process of settlement. (*U.S. Department of Agriculture.*)

Fig. 322. Mixed broadleaf-deciduous forest (chestnut-chestnut oak-yellow poplar) in North Carolina. (*U.S. Forest Service.*)

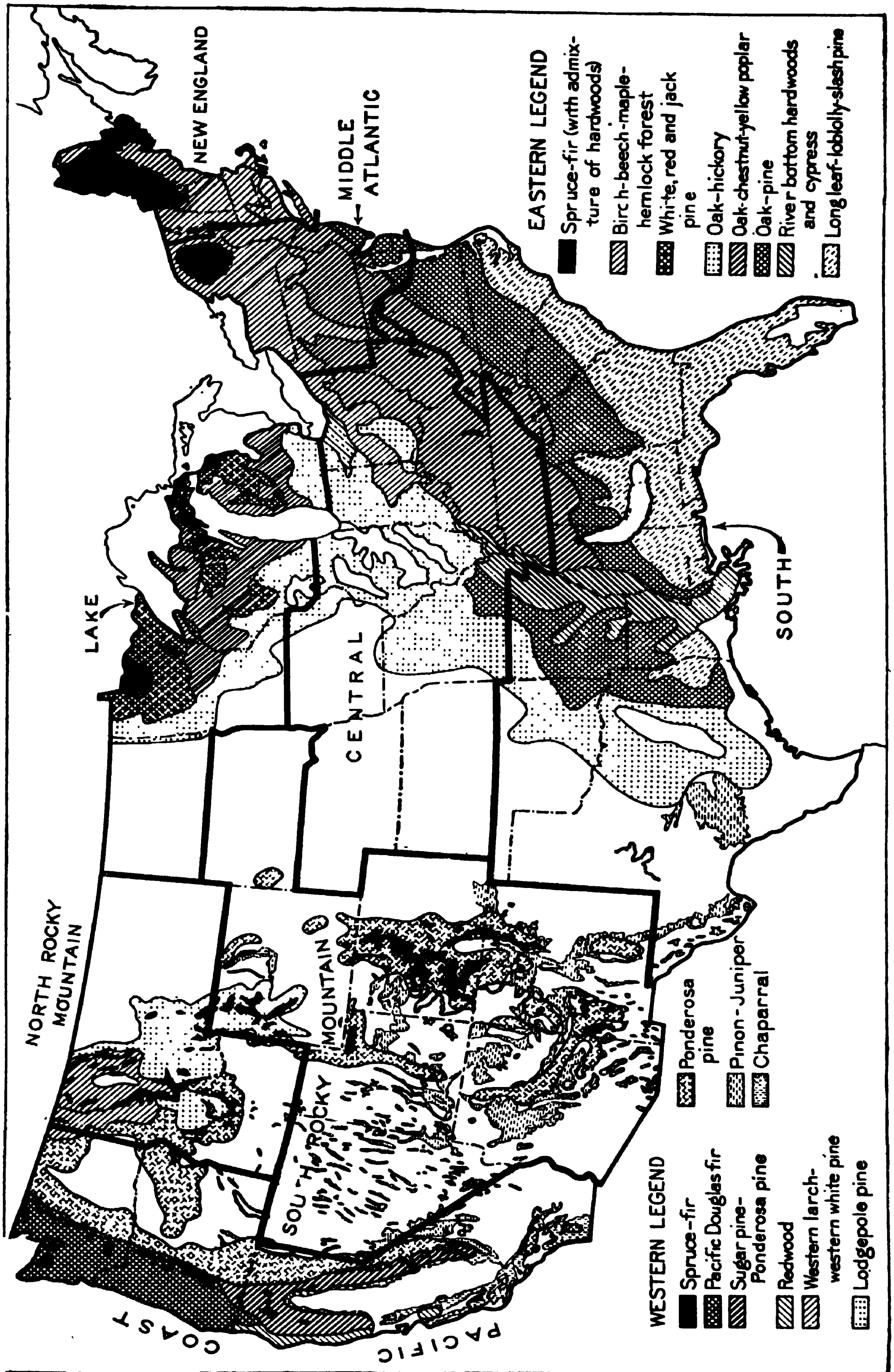


Fig. 323. Forest types in the United States. (*After Zon and Sparhawk.*)

Fig. 324. An air view of the swamp taiga of western Siberia. This subarctic region did not suffer glaciation. (*Courtesy of American Geographical Society of New York.*)

Fig. 325. Taiga in the ice-scoured region of Canada (*cf.* Fig. 324). (*Royal Canadian Air Force photograph*).

a result there is usually less surficial vegetation, a minimum of bacterial activity, and smaller accumulations of humus in the soil.

595. *Subarctic Conifers.* Conifers reach their maximum development, as far as areal extent is concerned, in the severe subarctic regions of North America and Eurasia, where they form wide and continuous east-west forest belts stretching from coast to coast (Figs. 324 and 325). To the subarctic coniferous forests have been given the name *taiga*. On their northern frontiers they make contact with the treeless tundra, a region thoroughly hostile to trees. The Eurasian taiga forms the single largest continuous forest area on the earth. Conifers (larch, spruce, fir, pine) predominate, although deciduous trees (alder, willow, aspen, birch, mountain ash) are scattered throughout, individually as well as in thickets or clusters. The latter are characteristic of low swampy areas and of regions bearing a second growth. Species are few in number. Xerophytic character is conspicuous, for taiga soils are physiologically dry much of the year, water being freely accessible at the roots only during the short warm

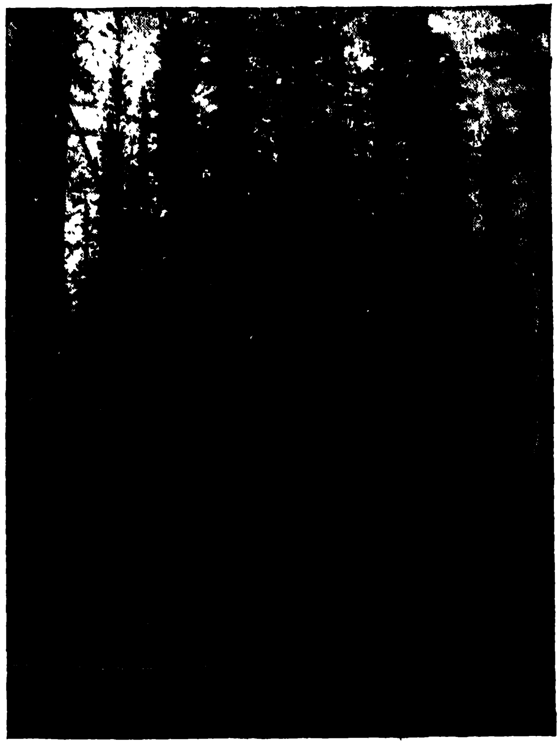


Fig. 326. Side view of the taiga in Yukon, Canada. Note the small size of the trees. (*U.S. Forest Service.*)

Fig. 327. Dense stands of fir on the mountains of Oregon. (*U.S. Forest Service.*)

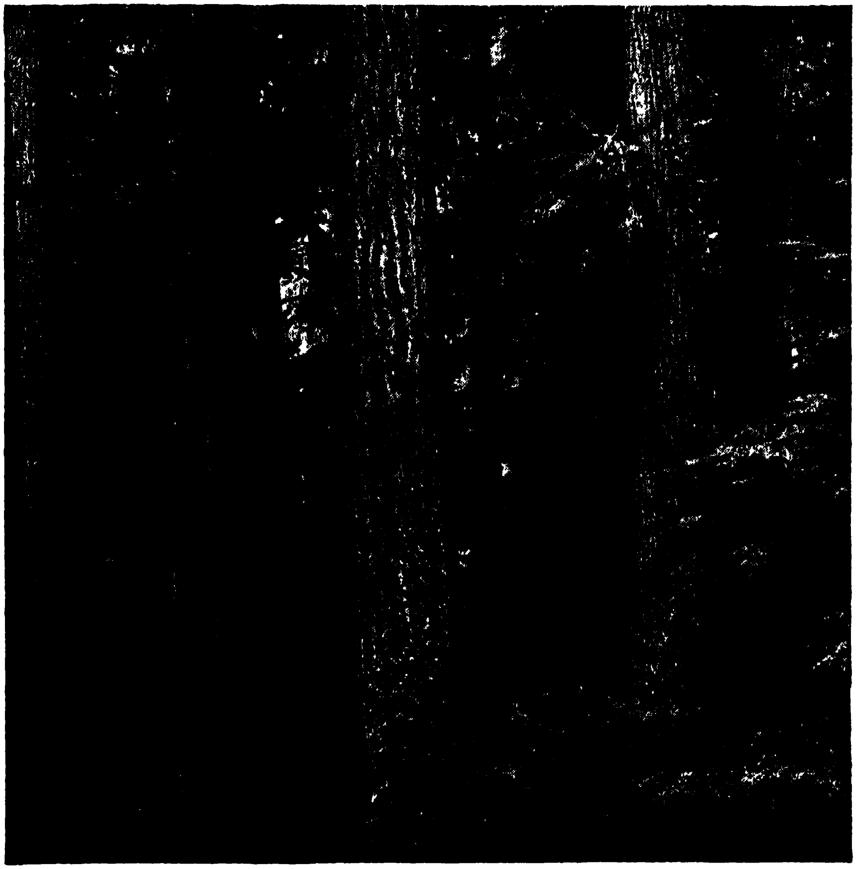


Fig. 328. Interior view of Pacific Douglas Fir forest. Trees are of large size, and the stand is dense. (*U.S. Forest Service.*)

season of 3 to 5 months. Even in summer absorption of water is retarded by the coolness of the soil and the acidity of the humus which accumulates in the deep, cool shade. In these regions of long, cold, dry winters and short cool summers, trees are relatively small in size, usually not over 1½ ft. in diameter, and growth is slow (Fig. 326). Wet swampy areas covered with sphagnum moss, and containing such trees as spruce and balsam, are numerous, these spots being designated as *muskeg* in North America. On the shaded forest floor vegetation is meager, mosses and lichens being the most common plant forms, and sometimes even these are stifled by the thick blanket of slowly decomposing needles. Little organic matter is made available to the soil, for needle leaves are a poor source of humus to begin with, while the low temperatures and deep shade act to retard decomposition and discourage the activity of soil fauna. Animal life is not so abundant as in the middle-lattitude forests farther south, although trapping is an important occupation, and the taiga is one of the principal sources of furs. The long-continued cold tends to make for heavy pelts. Wolf, bear, fox, otter, mink, ermine, squirrel, lynx, and sable are representative animals.

596. *Conifers in Lower Middle Latitudes.* South of the great belts of subarctic conifers are other areas of needle trees which, although less extensive, are nevertheless more valuable forest regions. This comes about as a result of their being composed of larger trees and superior timber species and at the same time being more easily accessible. In western North America broken belts of conifers extend southward from the taiga following the rainier highland chains

plants at the surface of the ocean are the principal basis of sea life, for upon them myriads of small sea animals, such as Crustacea, feed, and they in turn are the most important sources of food for fish. Thus the plankton mass, composed of tiny plant and animal forms, is the principal reservoir of fish food. On the whole it is most abundant in coastal waters.

605. Edible Fish. The greatest resource of the oceans is edible fish, and yet the world's annual catch, amounting roughly to $700,000,000, ordinarily does not equal the value of the American corn, cotton, hay, or wheat crop. Although seas cover approximately three-quarters of the earth's surface, the areas frequented by edible fish in large numbers, and in which they are most easily caught, are very much restricted. The type regions of fishing concentration are (*a*) the shallow coastal waters covering continental shelves and (*b*) the broad submarine elevations, called banks, in close proximity to the coasts. Most of the world's fishing is done along the margins of continents in waters whose depths are less than 200 fathoms (1,200 ft.). This concentration of fish in shallow coastal waters reflects the relative abundance of their food supply in that location. This exists in the form of (*a*) floating plankton, (*b*) waste received from the adjacent land, and (*c*) rooted algae in the shoal waters near shore.

606. *World's Important Fisheries in Nontropical Waters.* The commercial fishing grounds of world importance are, in general, outside the tropics and in the Northern Hemisphere. It is often stated that tropical waters contain fewer edible fish than those farther north, and a common explanation given is that there is a greater concentration of plankton in cooler waters. This notion that both plankton and fish are less abundant in tropical and Southern Hemisphere seas is open to question. Certain it is that in the low-latitude seas the number of fish species is greater than it is in middle and higher latitudes. On the other hand, it is probably true that there are no such regional concentrations of a few valuable and better known species as there are farther north. Tropical fish suffer the further handicap of being softer and inclined to spoil more readily so that they are commercially less valuable. Locally, however, the fish resource of tropical coastal waters may be of highest importance to the native inhabitants. The outstanding significance of Northern Hemisphere fisheries, in all probability, is associated with the presence there of large areas of shallow water along the margins of the continents.

607. *Fishing Regions of World Importance.* Organized commercial fishing on a large scale is concentrated in four regions: (*a*) the coastal waters of Japan, Sakhalin, and eastern Siberia, (*b*) those of New England, Maritime Canada, and Newfoundland, (*c*) the coasts of northwestern Europe, and (*d*) the Pacific coasts of northwestern United States, Canada, and Alaska. Not only is the continental shelf around Japan and off eastern Siberia one of the world's most important fishing grounds, but Japan is also the world's most important fishing nation, her catch making up approximately one-quarter of the world's total. The annual catch of Japan is three to four times that of the United States or Great Britain, which are her closest rivals. Cool and warm currents are both present, herring being the principal food fish of the former, and sardines, bonito, tunny, and mackerel, of the latter. More than in most countries fish is a staple article of diet in Japan; in fact it is the main source of animal foodstuffs. Large quantities of fish are also used as fertilizer in this land of ultraintensive agriculture.

The life of New England, Newfoundland, and Maritime Canada is closely associated with the development of the fish resource. Fishing here is carried on both in the shallow inshore coastal waters, and in the region of the banks, the latter being more important. The North Atlantic Banks, extending as broad submarine elevations from Nantucket to the eastern coast of Newfoundland, are the world's greatest cod fisheries. Herring, mackerel, haddock, and halibut are a few of the other commercially valuable species of this western North Atlantic region. Fish such as herring and mackerel, which live relatively near the surface, are caught mainly by drift nets and lines. Other fish, represented by cod, halibut, and haddock, travel and feed

in deeper waters (200 ft. or more below the surface) and are more difficult to catch. These are taken (*a*) by hand lines operated from the decks of fishing boats, (*b*) by long trawl lines buoyed up at both ends, to which are attached several hundred shorter perpendicular lines, and (*c*) by trawl nets. The latter are in the form of huge cone-shaped bags, and, because of their size and weight and the depth at which they are operated, they must be hauled by steam-powered vessels called trawlers. Shell fish, especially oysters, obtained from the coastal waters of the Middle Atlantic States, are another important element of the western North Atlantic fisheries. Chesapeake Bay is the principal focus of this development.

Along the Pacific Coast of North America salmon is by far the most important fish, and from that region comes practically all the world's canned salmon. The habits of this fish make it particularly easy to catch, and this fact greatly increases the danger of salmon extermination. Each spring and summer millions of adult salmon, driven by the urge to spawn, leave the ocean and ascend the streams emptying into the Pacific from northern California to the Bering Sea. Before winter sets in, each salmon reaches the river or lake of its birth and there in the sand or gravel deposits its eggs. This fact that, when life is about spent, the adult salmon returns to the spot of its birth, makes it particularly easy to catch these fish in nets as they ascend the coastal rivers. The result has been a rapid rise of the salmon industry on a particular river and then a serious decline. By 1920 the salmon industry of North America was threatened with depletion. As a result of conservation measures established since that date, salmon runs have increased again in some of the streams.

More than 200,000 men, drawn chiefly from Great Britain, Norway, Holland, and France, annually engage in fishing in the stormy waters of the eastern North Atlantic. In this region weather is characteristically bad and the seas rough so that the loss of life among fishermen is high. Fishing goes on throughout the year, although spring, when plankton is most abundant along the coasts, is the season of greatest activity. Herring, cod, and mackerel are the principal fish. Northwest Europe is the greatest fish-exporting region of the world, the annual shipments often exceeding 1,000,000 tons.

608. Sea Mammals. In addition to edible fish, there are other sea animals, such as seal, walrus, and whale, which are valuable for their skins, oil, bone, ivory, or flesh. Without exception, each of these animals has been the object of such ruthless slaughter that it has led to serious depletion of its numbers, and in some instances near extermination has been the result. The fur seal is an inhabitant of the waters and coasts of the North Pacific, more especially the Bering Sea, and those bordering the Antarctic continent. Desire for profits led to such reckless killing of these valuable animals that the industry has been practically ruined. To prevent complete extinction fur seals are now protected by international agreement. Arctic seals, valuable principally for their oil and skins, are caught off the northeast coast of North America as they drift southward on the ice floes in early spring. Their numbers, too, have been greatly reduced. A native of shallow coastal Arctic waters and sought for its ivory and tough hide, the walrus has suffered the same fate as the seal. Formerly all these animals furnished one of the principal sources of food for the natives who occupied the Arctic coasts. Whales inhabit both Arctic (North Atlantic Arctic and North Pacific Arctic) and Antarctic seas. Their particular value is for oil. In the Arctic seas whales have been so greatly reduced in numbers that the whaling industry has all but disappeared. It is now at high tide in Antarctic waters, but unless international regulatory measures are taken to conserve the whales of those regions the history of the Arctic industry will be repeated. In 1937–1938 the number of whales killed reached the record figure of over 51,000.

CHAPTER 24: *Soils: Their Nature and Classification*

609. The Soil Resource. Soil and water are the two most necessary earth resources. Prior to any requirement of building material, fuel, or power and therefore prior to the requirement of coal, metal, or stone is the need for these two fundamentals of existence, the sources of the most primitive forms of food and drink. Which of the two is more essential cannot be said. For food production each is useless without the other. Some regions are richly endowed with both soil and water and are capable of supporting large populations. Some have abundant soil but no water, whereas others have abundant water but little if any soil. A few, such as desert hamada, practically are devoid of either (453). Unlike the air, therefore, the soil may not be taken for granted as one of the omnipresent items of regional equipment. It differs greatly from area to area, not only in quantity but in quality and inherent capacity for serving the needs of man.

610. The Soil and Its Parent Material. A soil is a natural complex of mineral and organic substances suited to the growth of plants. It was not created in the beginning exactly as it is now but rather is the product of development, or evolution. It is evolved from a parent material, which generally is the mantle rock, or regolith. It is developed by slow processes, which include ordinary physical and chemical weathering and, in addition, some that go on only under the influence of living organisms. The organisms concerned include higher animals, earthworms, abundant forms of microscopic life, and especially the kinds of natural vegetation the remains of which have been deposited upon and within the surface soils for thousands of years. For this reason the soil is considered to extend downward only so far as abundant organic life penetrates, generally not more than 5 to 8 ft. Below the soil, whatever its thickness, is the parent material of the soil, and below that is solid rock (Fig. 133).

Since, therefore, the regolith is derived by processes of weathering from the solid rock, and soil is evolved from the regolith, it is necessary to distinguish between the processes that accumulate the parent material and those which make the soil. The former have been discussed under the head of the gradational processes (360). Attention will be directed here to the processes that make the soil and to some of the different properties that they impart to it. Before entering upon that discussion it is necessary to inquire briefly into the general nature of the chemical constituents and physical properties of soils.

Fundamentals of Soil Chemistry

611. Earth Minerals and Soil Components. The essential ingredients of soils are mineral substances, organic compounds, living organisms, water, and air. The bulk of most soils is made up of earth minerals. They are the same minerals as those discussed under the head of earth materials (329), and they are comprised of the chemical elements there indicated (328). In the case of any given soil it may be supposed that its mineral components originally were the same as those of its parent material, the regolith which lies underneath it. From its mineral components the soil derives not only a considerable part of its mass but also some of its elements of fertility and some of its peculiarities of physical constitution.

612. Soil Elements. It was noted previously that of the many chemical elements found in the

earth's crust, only a few are abundant. The same is true with respect to soil constituents. The most abundant soil components are the elements oxygen, silicon, aluminum, and iron, and they are combined in the common minerals, or their weathered derivatives, which give bulk to the soil. However, they are not necessarily the most important elements from the standpoint of the things that grow in the soil. Plants are known to require for their proper development about 15 different elements, and scientists are discovering that still others play some essential part in plant growth. Of this number some are supplied as gases directly from the air or as gases dissolved in the water of the soil. Others, including nitrogen and the necessary mineral elements, such as calcium, potash, and phosphorus, are taken in solution from the soil itself. Some of the mineral elements either are required in such small quantities or usually are present in the soil in such large quantities that their supply is not a matter of much concern in agriculture.

613. Supply and Removal of the Mineral Elements. The mineral elements in the regolith can be absorbed by plants only when they are included in the soil solutions. They are reduced to this state by complicated weathering processes which disintegrate and decompose them into smaller and smaller particles. These pass through the stage of fineness called clay and ultimately they reach a submicroscopic size and undergo chemical change. In this state they combine with water and become gluelike and are known as *colloids*. It is believed that much of the nature of a soil, its fertility and agricultural character resides in its colloidal portion. The body of the soil will normally contain, therefore, particles of fresh and unweathered mineral, partially decomposed particles, and others grading down into the colloidal state. The larger particles furnish a reserve of mineral elements which are slowly made available for plant use by a continuation of the weathering processes.

Since plants absorb part of their sustenance in the form of dissolved minerals, it follows that, upon their death and oxidation, these soluble mineral substances also are returned to the soil in the form of ash. Some part of that supply is used again by other plants, but some is removed in solution by percolating ground water and, in humid regions, is carried away in the drainage waters. In arid regions, where there is little downward movement of ground water, the rate of removal of soluble salts is low, and there may be appreciable—in spots even a harmful—accumulation of soluble minerals in the soil. In humid regions, however, the loss by leaching is heavy, and soils eventually would be entirely depleted were it not for reserve supplies present, but in unavailable form, in the unweathered rock minerals of the soil.

The slowness with which the new supply is made available often leaves humid-land soils that are continuously cropped deficient in one or more of the critical elements. The deficiency may, of course, be made up by the application of mineral fertilizers (722) but at great expense. Alternative means are commonly employed. One of the methods is called *fallowing*. That is the practice of allowing land to lie idle during one or more years in order that mineral decomposition may make available a sufficient amount of the critical elements to grow a crop. Other means include processes of conservative agriculture in which a part of the minerals removed from the land in the form of crops is returned to it in the form of animal manures mingled with straw and other plant refuse.

614. Organic Matter in the Soil. Although it is true that the bulk of most soil is made up of minerals, it is the presence of organisms and of organic matter, the source of soil nitrogen, that makes soil essentially different from regolith. The organic matter is derived from plant and animal substances which, in addition to their small amounts of mineral ash, are made up largely of carbon, nitrogen, and water. Nitrogen is essential to plant growth. There is an inexhaustible supply of it in the air, but that is not available to plants, which must take it from the soil in solution. It is made available in the soil in the soluble form of nitrates largely through the work of microorganisms, some of which are able to take nitrogen gas from the soil air and transform it. The leguminous and some other

plants play an important role in this connection since their roots act as hosts to these nitrogen-transforming bacteria. Other soil organisms make nitrogen available through their ability to decompose the complicated organic remains of plants and animals which are then incorporated in the soil. Under conditions of low temperature the decomposition is slow, but under warm and moist conditions it is rapid, and both the end products of the decomposition and their relation to the characteristics of soils are different from those formed under low temperatures. In the early stages of the decomposition of plant remains one may recognize in the soil some fragments of plant tissue, but later these are reduced to a state of division so fine that they assume a jellylike consistency and are of highly complex physical and chemical properties. Finally this material also reaches the colloidal state and is taken into solution. The abundant organic matter of some soils includes the accumulations of many years. Some of it is recent and only slightly decomposed, while the larger part is so far decomposed that it exists in the jellylike or waxy colloidal form. This substance is usually referred to as *humus*.

The dissolved organic matter of the soil is constantly drawn upon by plants to furnish the nitrogen required by them, but if a proper amount of raw organic matter is added to the soil each year it gradually decomposes, and the humus supply is maintained. Some soils have by nature very small amounts of humus, but others are richly supplied with it. Some, like peat soils, are made up largely of raw or little-decomposed organic matter which has not yet reached the condition of humus.

The part played by the organic material of the soil in maintaining soil fertility is exceedingly complicated, but it includes the following: (*a*) The organic material, when finally it is taken into solution, furnishes food to plants, not only nitrogen but also such quantities of phosphorus, potassium, and calcium as remain from the plant and animal tissues from which it is derived. (*b*) The processes of decomposition yield organic acids which aid in the solution of soil materials. (*c*) Organic material is necessary to the existence of the microorganisms of the soil, those which break down the organic compounds, and also others which are beneficial to plants. (*d*) The jellylike nature of the humus causes it to have a high capacity for the absorption of water and of substances dissolved in water. This tends not only to maintain a supply of soil water for plants but also to retard the removal, or leaching, of dissolved minerals until plants can use them. (*e*) The presence of humus promotes an arrangement, or structure, of the soil particles which is favorable to cultivation and plant growth.

615. Acid Soils and Alkaline Soils. Soil water, through the solution of carbon dioxide from the air and the addition of the acid products of organic and mineral decomposition, tends to become a weak acid. Many soil constituents, such as lime, sodium, and others which may be called the alkaline earths, have basic reactions. In the processes of chemical weathering, the acid-soil waters attack the alkaline minerals, neutralize or dissolve them, and are themselves neutralized. In localities where ground water and the organic acids are abundant, they tend to neutralize and remove all the readily available alkaline substances, and thereafter the soil solutions have generally acid reactions. The soil, under such conditions, is said to be acid, or sour. Strongly acid soils generally are unfavorable to the existence of earthworms and various soil bacteria, especially those which transform atmospheric nitrogen. Acid soils are likely, therefore, to be poor in available nitrogen although they may contain large amounts of undecomposed organic remains.

In dry regions the weathering of rocks furnishes alkaline earths, but supplies of both soil water and organic acids are limited. Consequently the soluble alkaline substances are not all leached out but tend to accumulate in the soil and give it an alkaline reaction or to become strongly charged with saline matter, including common salt. In some regions the supply of soil acids is just sufficient to balance, or neutralize, the alkaline substances as they are supplied from the soil minerals. The soils of such regions give neutral reactions and are well suited to the

growth of most agricultural plants. Many crops will grow in soils which are either slightly acid or slightly alkaline. Some show a marked tolerance of acid soils; others of alkaline soils. However, there are some localities that have soils which are so highly acid, and others in which the soils are so strongly alkaline, that the common crops will not grow in them. They produce only weeds or shrubs of little value or nothing at all. The problem is not entirely simple, since there are various kinds and conditions of soil acidity and alkalinity. In general, however, the acidity of a soil may be reduced or corrected by the addition of an alkaline substance, especially pulverized limestone. The excess of alkaline or saline substance, which is found in the soils of some arid lands, usually is capable of removal by the application of abundant irrigation water and the provision of good drainage. This practice tends to dissolve the excess and to carry it away in the drainage waters.

From the above it is apparent that the factor which more than any other determines the acidity or alkalinity of the soil is the degree of leaching. This in turn depends largely upon the rainfall but also on temperature, vegetation, and other factors. Humid regions have in general acid soils, whereas those of dry regions tend to be alkaline or saline.

Fundamentals of Soil Physics

616. Important Physical Properties of Soils. The agricultural utility of soils is not determined by their chemical properties alone or by the mere presence or absence of the critical elements of soil fertility. Certain physical characteristics have quite as much to do with their ability to produce crops abundantly. The more important among the various physical properties are (*a*) the size of the soil particles (soil texture), (*b*) the quantity of water included in the soil and the manner of its retention, (*c*) the manner of arrangement of the soil particles with respect to each other and the volume of the pore space included between them (soil structure), and (*d*) the soil color.

617. Soil Texture. The mineral particles of which soils are largely composed vary greatly in size from one locality to another and often from the surface downward also. In some soils coarse particles are predominant; in others, exceedingly fine ones; whereas in many there is an intimate intermingling of particles of various sizes. The quality imparted to a soil by the predominance of one size of particle, or by a mixture of sizes, is called its *texture*. Some of the commonly recognized textural classes are coarse sand, fine sand, silt, and clay. The particles thus described may vary in size from diameters of about one millimeter in coarse sands to diameters of less than one-five-hundredth of a millimeter in clays. The clays include the finest particles capable of being seen, even with a microscope. However, other still smaller particles exist—the inorganic colloids, or colloidal clays. Soils may, therefore, include in their composition visible particles of mineral matter, visible particles of organic matter, colloidal clays, organic colloids, and material in solution. The colloidal substance appears to exist in part independently of the soil particles but mainly as a gelatinous coating upon them. Finely divided soils have larger total surface areas than do soils of coarse texture. It is from the surface areas of soil particles and from the films of soil solution and colloids upon them that plant roots draw much of their nourishment. Therefore, fine soils, having large surface areas, provide large feeding areas for plant roots.

618. Water and Air in the Soil. Plants absorb their food from the soil solutions, but only a few crop plants are able to thrive in soils in which the pore space between the soil particles is completely filled with water all the time. Most of them require soils containing both air and water. However, the yearly water requirement of plants is large. It has been shown by experiments to be, for various crops, as much as three hundred to one thousand times the dry weight of the mature plant. Water exists in the soil in various relationships.

The water of the soil is supplied from the atmosphere. Even in regions that are nearly rainless, the soil may not be absolutely dry, for it is capable of taking from the air that penetrates it a minute quantity of water vapor. This

is held as a microscopic film of water molecules upon the outsides of the individual soil particles and especially by the soil colloids. It is known as *hygroscopic water*. It is more abundant in humid regions than in dry ones, in fine soils of large surface area than in those of coarse texture, and in soils of high colloidal content than in those low in colloids. Hygroscopic water adheres firmly to the soil particles, does not move from one part of the soil to another, and is very resistant to evaporation.

Soils that are moistened frequently have thicker films of water about their particles. This is called *capillary water*. It is held upon the soil particles by surface tension and is absorbed by the soil colloids in great quantity, causing them to swell and giving them their jellylike consistency. The capillary film upon ordinary soil particles does not fill the pore spaces between them but exists together with soil air (Fig. 339). It is, however, with its dissolved materials, readily available to plants. When the supply of capillary water is abundant, it moves slowly downward under the pull of gravity. When the supply is diminished by plant use or surface evaporation, it may move horizontally, or even creep upward, under the pull of its own surface tension. In fine-textured soil, water may be drawn upward in this manner from depths of a few inches or several feet, although in periods of extreme drought it may not rise fast enough to furnish plants a sufficient supply. In soils of coarse texture, both the amount and the movement of capillary water are limited, and they require frequent moistening to keep them from being droughty. Fine soils of high organic content are capable of holding great quantities of water on their large surface areas and in their organic colloids and colloidal clays, and they may continue to provide moisture for plant roots even during protracted droughts. It is this property which makes them plastic, sticky, and retentive of water, while coarser but equally moistened soils are crumbly and quickly dried out. It also causes them to swell when they are wet and to shrink and crack open when they are dry. Some fine-textured soils of high colloidal content, especially in regions of savanna climate, crack open so widely during the season of prolonged drought that much of the surface material crumbles and falls or is blown into the cracks. This causes a sort of natural overturn or circulation of the upper soil, which is sometimes said to "plow itself."

Immediately following protracted rains the pore spaces of soils may be completely filled with water, displacing the air. In this condition there is water in excess of that which can attach itself to the soil particles, and the surplus will move downward into the zone of ground water. This may be called *free* or *gravitational water*. In low sites, where the ground-water table coincides with the land surface, or in localities where water is prevented from downward movement by an impervious layer in the subsoil, there may be a permanent supply of gravitational water at the surface. That will create a waterlogged or swampy soil in which most cultivated plants will not grow. Where good underdrainage exists, the gravitational water moves downward, quickly in soils of coarse texture or open struc-

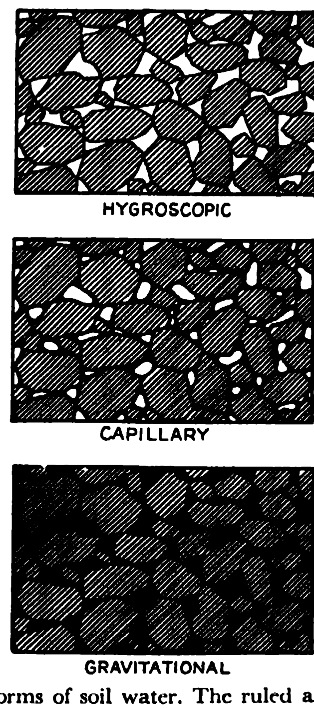


Fig. 339. Forms of soil water. The ruled areas indicate soil grains, the blackened margins water, and the white areas air spaces.

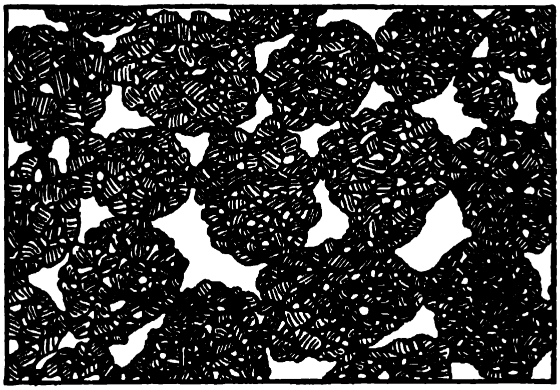


Fig. 340. A diagram to illustrate structure and pore space in a flocculated soil.

ture and slowly in those which are fine and compact.

It will be seen, therefore, that in all except coarse soils water moves both downward and upward. In humid regions the supply of surface moisture is sufficient to keep the downward movement considerably in excess of that in the upward direction. In arid regions, however, the supply of precipitation is insufficient to provide enough water to cause a gravitational movement down to the level of a deep ground-water table. Surplus gravitational water may distribute itself downward for a few feet, but later it creeps upward as capillary water bringing with it salts dissolved below. It is by this means that lime and other salts accumulate in the upper horizons of dry-land soils, while in humid-land soils they are leached out and carried away in the underdrainage.

619. Soil Structure. Not all the important physical conditions of the soil may be explained in terms of soil texture. If that were true, fine-grained soils would always be compact and impervious to water, but such is not the case. Instead, it is found that many clays and silty soils have an arrangement of particles that is permeable to water, admits abundant soil air, and prevents the soil from being heavy, tough, or cold. This property of a soil is called its *structure*. A good soil structure is attained by the association of soil particles into groups or granules, which then behave as individuals. These groups, which are sometimes called *floccules*, may themselves be arranged into larger compound groups and thus build up a structure in which there are pore spaces between the particles in the floccules and larger spaces between the floccules or larger groups (Fig. 340). Structures of this kind are not present in all soils. They may be produced in certain soils by proper management, and they may be destroyed by improper treatment. They commonly are found in soils of fine texture and good colloidal content, but sandy soils are essentially without structure, each sand particle acting as an individual.

620. *Pore Space in Soils.* Soils of fine texture, in which the particles are well flocculated, build up internal structures in which the pore space available for air, water, and root penetration is much greater than in most structureless soils. In the latter the actual amount of pore space is believed to be sometimes less than 20 per cent of the soil volume. In highly flocculated clays it may exceed 60 per cent. A flocculated clay is, therefore, permeable and open in structure; but if its good structure is lost, a clay becomes very compact, tough, and highly impermeable, because of the smallness of its pore spaces and their partial filling by colloids which prevent the ready circulation of water and air. Most agricultural soils include amounts of pore space ranging between 35 and 50 per cent of the soil volume. However, the porosity of the upper and lower portions of the same soil may differ considerably, and time may change the porosity of a soil through changes in chemical composition or soil management.

A good structural arrangement of soil particles, with ample pore space, is promoted by the presence of lime and by the growth and decay of plant roots or the addition of organic fertilizers. These form films of colloidal and limy material which coagulate into waxy cements that attach the soil particles together, without filling the pore spaces, and thus keep the floccules from falling apart. The desirable structure may be destroyed by permitting the exhaustion of lime and organic matter from the soil. With the depletion of those materials the colloids lose their waxy coagulated form and become dispersed and are removed from the soil by under-

drainage. The weakened cements permit the soil granules to fall apart, and their disintegration is aided by rains beating upon the bare earth or by cultivation when the soil is very wet. A badly deflocculated clay, when dried out, is difficult to till and breaks up into coarse lumps which do not make a good seedbed. In a soil of good structure the floccules maintain their identity under cultivation but separate into groups of various sizes and shapes which are sometimes described by appropriate terms, such as mealy, platy, granular, buckshot, or lumpy structures.

621. Soil Color. In many regions the color of the soil is a conspicuous feature of the landscape. Important as that is to the geographer, it is not its only significance. Soils range in color through a wide variation of shades or tints from white to black. Among the commonest colors are dull shades of red, rust brown, or yellow. These are due to the different forms, degrees of hydration, and intensities of the oxides of iron which exist as thin coatings or stains upon the soil grains. In some humid regions a whitish color commonly results from a lack of iron oxides. In arid regions the same color may denote a harmful concentration of soluble salts. Black and dark-brown colors in soils usually, but not always, denote a considerable content of organic matter. In many soils two or more color-forming elements are present, giving rise to intermediate colors, such as yellowish brown or grayish brown. Because soil color usually has some basis in physical or chemical conditions, it is commonly assumed with good reason that dark soils are productive and that the light-colored ones (red to white) are, by comparison, unproductive. Although this is true of many soils, it is not always so.

The color of soil changes, not only from place to place but also from the surface downward and from one time to another. Surface soils, in some regions, are prevailingly unlike their subsoils in color, and wet soils generally are darker in color than the same soils when dry. The prevalent color of the soil of a region is, therefore, some indication of the general nature of the physical and chemical properties of the soil there, and it is used as a convenient designation for soils of the different major soils groups of the world, which are to be discussed later. Soil color has some relation to soil temperature also. Dark soils are better absorbers of solar radiation than are those of light color, and therefore they tend to be warmer. However, the warmth of a soil is even more dependent upon the circulation of air and water in it. For that reason a light-colored but permeable sand may warm up quickly in spite of its color.

FACTORS IN SOIL FORMATION

622. Parent Materials and Soil Formation. It has been noted previously that soil is developed from a parent material, which is the regolith. Although the processes of development, when carried to completion, impart new characteristics to the soil complex, they do not in all soils erase completely the effects of strong contrasts in the parent materials. Some of the latter change rapidly, whereas others are highly resistant to change. Some are highly complex mineral compounds; others are simple. Some are high in lime, others low. Sandy soils develop from very sandy parent materials regardless of environmental conditions. The effects of parent material are generally more visible in young and imperfectly developed soils, such as river alluvium, than in old ones.

623. The Climatic Factor in Soil Development. Climate influences soil formation both directly and indirectly. Directly it affects the weathering of rocks, the percolation of water through the soil, and the work of the gradational agents. The soils of humid regions are more leached than those of dry lands. They are commonly more acid also and usually have little available lime, whereas those of arid lands are little leached and usually contain lime or soluble salts. Climate also affects the development of the soil through its seasonal variations in temperature and rainfall. Prevailingly high temperatures promote rapid chemical change in the soil, and cold slows it down. Alternating seasons of rain and drought cause soils to develop color and composition different from those of soils of continuously rainy regions. Wind acts as a dry-

ing agent in soil formation, and deflation and wind deposition are important soil-forming processes in some localities. These are but a few of the many ways in which the climatic elements are concerned with the processes of soil development.

624. The Biologic Factor in Soil Development. Both plants and animals play important parts in soil formation. Microorganisms (bacteria, fungi, protozoa, etc.) cause the decay of plant and animal remains and aid in their transformation into humus. Some kinds transform atmospheric nitrogen into soil nitrogen, as previously noted. These minute organisms live and die in such vast numbers (billions per gram of soil) that their own bodies also make an important contribution to the organic content of the soil. The roots of higher plants, such as grasses and trees, penetrate the soil and help to make it porous. When they die, they add organic matter within the soil. Deep-rooted plants bring mineral solutions up from the subsoil and build them into their tissues. When these die and decay, the minerals are added to the upper soil layers. However, the organic acids provided by plant decay in humid regions hasten the soil-leaching process. The work of worms is most important in mixing organic remains with the mineral soil constituents and in bringing subsoil minerals to the surface. Burrowing animals perform a similar service on a smaller scale, and all animals aid, to some extent, in soil formation when plant products pass through their digestive tracts and are returned to the soil for further transformation.

625. Surface Relief and Drainage as Factors in Soil Development. In addition to the other factors mentioned, the development of the soil is influenced by its physical site. This is because differences in surface slope may greatly affect the moisture and air conditions within the soil and the rate of its surface erosion. Ideal development is most likely to take place on rolling and well-drained uplands where there is free underdrainage and moderate surface erosion. On such sites the removal of old and leached surface material by erosion just about keeps pace with the downward progress of the soil-forming processes. Soils developing under such conditions are called *mature* soils. The soils of steep slopes, on the contrary, generally fail to develop to maturity because much rain water runs off the surface instead of percolating into the ground. This produces less leaching than is normal for the climatic situation, and it accelerates surface erosion, exposing the less developed lower layers. Lack of soil water and increased erosion reduce the density of the vegetative cover and thus modify the organic contribution to the soil development also. In poorly drained or marshy areas soils do not develop normally either. But in this case it is due to the slowness of leaching and to the fact that air cannot penetrate. Hence the usual organic processes are not carried out.

626. Time as a Factor in Soil Formation. The various factors involved in soil formation require time for the completion of their several processes. Hence, time is itself a factor. It is not a constant, however, since the other factors in combination do not progress at the same rates under different total environments. It is not possible to say how long it takes for a soil to develop. Some may reach a condition of balance with their environments in comparatively short periods, possibly in a few hundreds of years. Others may require thousands of years.

SOIL ZONES, SOIL PROFILES, AND SOIL CLASSIFICATION

627. Environment and Soil Zonation. Because of the fact that climate and vegetation are important factors in soil formation, there is a notable correlation between the world distribution of the great soil groups on the one hand, and that of the great climatic regions with their characteristic vegetational associations, on the other. The relationship is most clearly seen in the distribution of the maturely developed upland soils. Such soils show considerable uniformity within a given set of environmental conditions regardless of the parent materials from which they are derived, and they show likewise great differences in character under different climatic environments, even though their parent materials may

have been similar. Because they are characteristic of large regions or zones, which are more or less similar to the great climatic and vegetational regions, these are called the *zonal* soils. There are other soils which are found in all the climatic zones, and these are called *intrazonal*. In them some one factor, such as peculiar character in the parent material or poor drainage outweighs the effects of climate and all other environmental conditions. Still other soils seem to have no relation to the great soil zones. Generally they are found in areas of extremely youthful and undeveloped regolith, such as newly deposited alluvium, dune sand, or nearly bare rock. They are called *azonal* soils. These, the zonal, intrazonal, and azonal, are the soil categories of the highest order, and they are known as the soil *orders*. Each order may then be divided into *suborders* and the suborders into the *great soil groups*, of which there are 35 or more. These, or the ones among them which have the greatest geographical extent or significance, form the basis of the classification used in the following chapter of this book to distinguish between soils of large geographical regions.

From the standpoint of the agriculturalist a classification of soils which ended with the great soil groups would be wholly inadequate. It does not distinguish the details of difference upon which a small parcel of land depends for its suitability to one or another type of crop. The soil scientist, therefore, proceeds to further refinement. He divides each great soil group into *families*, the families into *series* of which there are hundreds in the United States alone. The series are divided into *types*, and there are thousands of these. They distinguish the soil differences of small areas, parts of farms, or even parts of fields. The families, series, and types, in the United States, commonly are given names derived from geographical localities where they were first recognized and defined. These place names give no clue to the relationships between a kind of soil and its characteristics.[1] The expert knows their characteristics and relationships and distinguishes them by their profiles.

The classificational processes of the soil scientist go even farther. Some soil series and types which were much alike under natural conditions show considerable differences according to the slope of the land when they are put under cultivation. These differences are recognized by the term *phase*. It may be noted also that, in a given locality, the related series and types of soils sometimes differ in profile, texture, and color mainly because of differences in the surface-slope and drainage factors in their formation. Such a related group or "chain" of soils is, by some soil specialists, called a *catena*.[2] It would be illustrated by the soil changes one would encounter in traversing a broad valley without a floodplain. In spite of general similarity as to type, the soils of the well-drained and eroded upper slopes almost certainly will be lighter in color and different in other respects from those of the valley lowland. In fact, there may be a nearly complete gradation from the upland on either side toward the lowland, and the local variations may be represented by the links of a slack chain hanging between gateposts.[3] This mode of soil grouping, valuable as it is for some purposes, does not coincide with the classification based on the great soil groups.

628. The Soil Profile. It will be apparent from the preceding discussion that some of the more important properties of zonal soils are acquired through *development*. A soil may be thought of as being somewhat like an organism, in that it has some qualities derived from its ancestry and some that come as a result of growing up under a given set of environmental conditions. Moreover, as a soil advances in age the qualities inherited from its ancestry tend to become less important in its make-up, whereas those which are acquired through development tend to assume greater importance.

In soils that have been subjected for a long time to the soil-forming processes, the qualities acquired through development are made evident by an arrangement of the soil into layers,

[1] T. M. Bushnell. Some Aspects of the Soil Catena Concept. *Proc. Soil. Sci. Soc. Amer.*, Vol. 7, p. 469, 1942.

[2] *Ibid.*, pp. 466–476.

[3] *Ibid.*

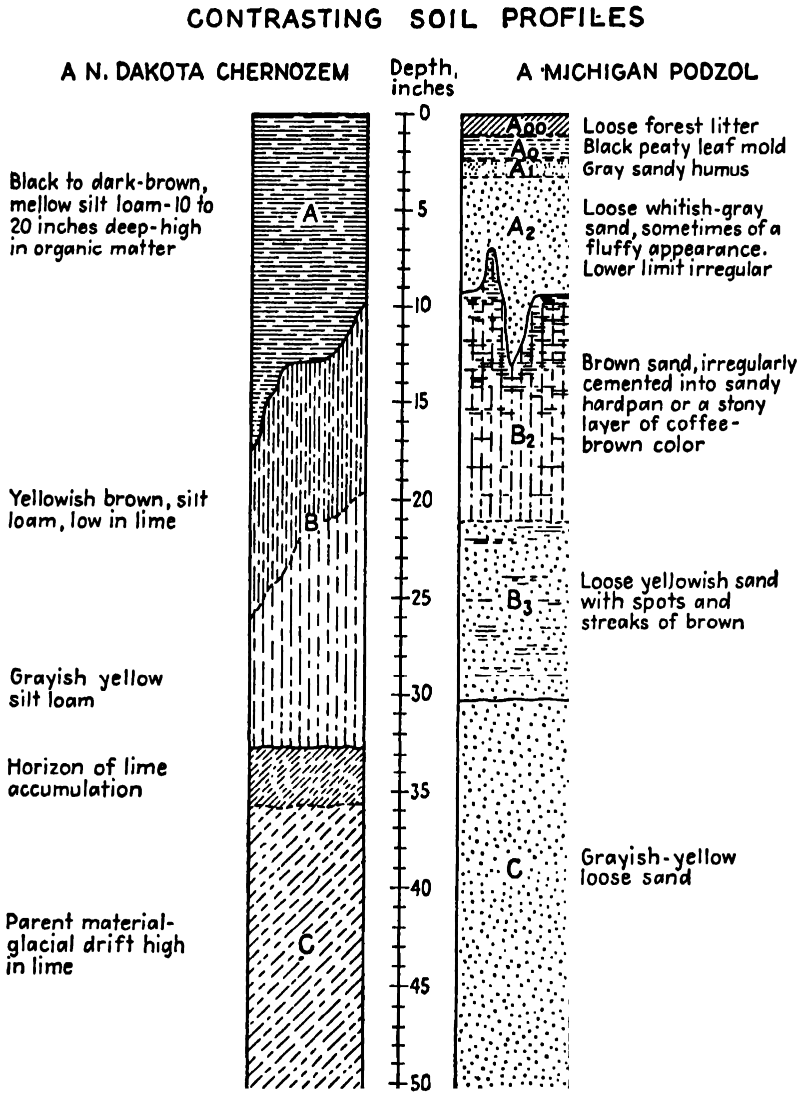


Fig. 341

or *horizons*, of different thicknesses and different chemical and physical properties. The succession of these layers, from the surface down to the underlying parent material of the soil, is called the *soil profile*.

629. Parts of the Soil Profile. Three horizons are commonly recognized: an upper, or A, horizon; an intermediate, or B, horizon; and a lower, or C, horizon (Fig. 341). In most soils the A horizon is distinguished from the others in color, texture, and structure. It is that part of the soil in which organic life is most abundant, and in grassland soils it may consist almost wholly of organic material. In forest soils it may have a thin layer of organic material, while its lower portion has lost some of its mineral constituents. In humid regions, generally, its development has involved the loss of something from its original composition. Through the work of percolating water some soluble material has been leached out, and some finely divided material has been carried out in suspension, or *eluviated*. The A horizon is, therefore, in most humid-land soils a horizon of leaching and eluviation and is left poorer in soluble substances and coarser in texture as a

result. The B horizon is, in contrast, one of *illuviation*. In it are deposited some of the materials carried in suspension from above and some parts of those carried in solution either from above or from below. It is a zone of enrichment, and in some soils it is made dense and impenetrable by its additions. The C horizon is the little-changed parent material, or regolith, from which the soil was derived. The thickness of each of these horizons varies greatly with the type of soil. In some they are thin, and in others so thick that, for purposes of minute description, each horizon is further subdivided.

630. Mature and Immature Profiles. Although uniform conditions of climate and natural vegetation tend to unify soil development, not all the soils of a given locality are likely to have the same profile. It was indicated above that a mature soil is the result of the slow evolution of a soil in its given environment. Such a soil may be said to have a *mature profile* and to represent the climax of development under the given conditions. The profile cannot develop ideally if the soil-making forces are interfered with by rapid erosion or rapid aggradation or are retarded by poor drainage. Therefore, many soils have not mature profiles. Instead, their horizons show evidence of disturbance or of arrested development, so that they remain immature. Some soils, such as deep sands, have developed no horizons and therefore have no profiles.

It cannot be expected, therefore, that all the soils of a district will have the mature profile typical of that district. In fact, in some considerable areas little if any mature soil is to be found. The normal processes of agriculture such as deforestation, plowing, and heavy grazing tend to increase the rate of erosion and to intermingle and otherwise destroy soil horizons. Indeed, the typical profiles of mature soils probably are nearly, if not quite, restricted to the virgin soils of a region, whether they are the soils of forest or those of prairie. Of their virgin soils many regions of high agricultural development have left only a few scattered remnants. Yet, when mature soils are present, they show significant similarities of profile over large areas, even when they are derived from widely different parent materials. Moreover, even the soils of incompletely or imperfectly developed profiles in a region commonly have qualities that indicate a developmental progress in the direction of the regional type.

631. The Great Soil Groups as a Basis of Soil Classification. Any attempt to secure a *world* view of the function of the soil as an element of earth environment requires that the vast number of types be grouped in a manner suited to brief and convenient description and such that general patterns of their world distribution may be understood readily. For this purpose a description and interpretation of the more distinctive of the great soil groups will suffice, and those chosen are the zonal groups. Classification on that basis rests upon the essential properties of all the soil horizons and not upon the surface layer alone, and it recognizes the effects of all the soil-making forces, especially climate. However, it should be emphasized that the groups selected for description are the zonal soils, that they are not the only soils in the regions, and that they are not everywhere the most productive soils from the agricultural viewpoint. Each region has also its intrazonal and azonal soils. These are not so easy to classify regionally but must be recognized as existing in association with each of the classes made.

CHAPTER 25: *The Great Soil Groups of the World*

632. The Great Soil Groups. Among the various factors that combine to transform regolith into soil, no other is more important than condition of climate. Quantity of soil moisture and prevalent conditions of soil temperature affect the soil directly, as has previously been indicated, and they also condition the growth of natural vegetation and the activity of microorganisms. It is possible, therefore, to distinguish clearly, upon the basis of their mature profiles, between the soils of humid forest regions and those of desert and steppe regions and, likewise, between the forest soils of the tropics and those of middle or higher latitudes.

The mature soils of humid regions generally have developed under natural vegetations of *forest or woodland.* There the organic matter is incorporated in the soil more slowly than in the grasslands. Therefore, the upland soils of humid regions as a whole are much leached, prevailingly light in color, and characterized by a comparatively low content of both organic matter and mineral plant foods. However, the chemical nature of the soil-forming processes, and the results produced by them in terms of soil profiles, are notably different in warm humid regions from those which operate in cool humid regions. The dominant soilmaking process of the tropical and subtropical forest regions is called *laterization.* Through this process the organic soil material is rapidly mineralized and leached out, the basic soil minerals are lost, and even the silica is largely dissolved. When this process is carried on to its extreme development, there remain principally the hydroxides of aluminum and iron, and this residual material is called *laterite.* In the subarctic forest lands, on the contrary, the dominant soil-making process is called *podzolization.* Owing to differences in climate, its processes are unlike those of laterization. Half-decayed and acid organic matter accumulates on the top of the soil. The upper soil is leached of its iron and aluminum compounds, and the remaining material is high in silica. In the subsoil there is an accumulation of finely divided organic matter, iron, and other mineral compounds leached from above and deposited below. The final product of this process is an acid and comparatively unproductive soil called *podzol.*

It appears, therefore, that laterites should be widespread in the humid tropics and podzols in the subarctic regions, but both these assumptions are not entirely supported by the facts. Although podzols do in fact occur widely in the higher latitudes, true laterite is not widespread in the tropics. Generally, however, tropical soils are lateritic in type and have progressed through some part of the lateritic process. Podzolization, on the other hand, is characteristic not only of the subarctic but, in modified form, extends into the forest regions of the lower middle latitudes and even to the tropics, where some soils of podzolic type exist beside, or have even developed from, those of lateritic origin. The notable thing in this connection, however, is that these two extremes do appear, that intermediate types exist, and that they form rude belts or zones corresponding roughly with the temperature modifications of the humid lands. These are the soil zones.

The mature soils of subhumid and dry regions generally have developed under natural vegetations of *grass or desert shrub.* They are little leached

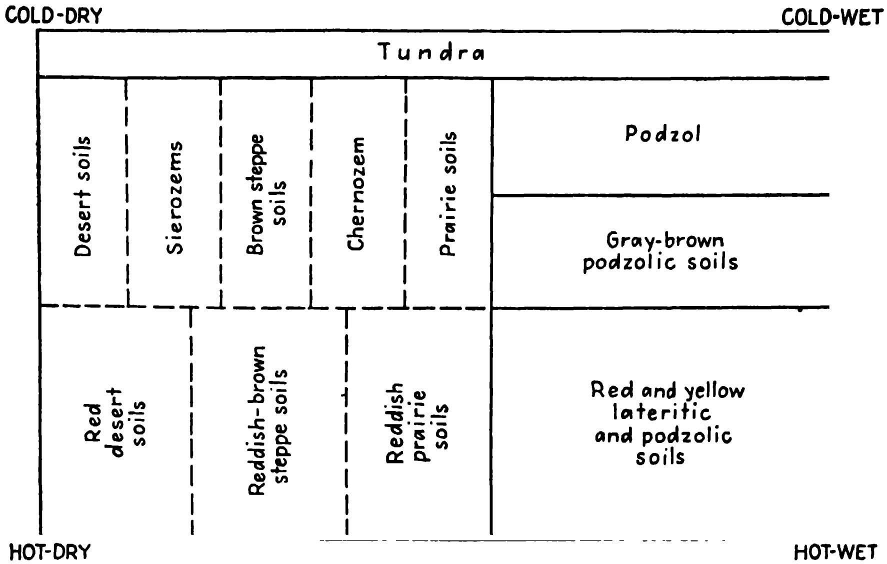


Fig. 342. A diagram to illustrate in a greatly simplified manner the general pattern of arrangement of the regions of the great soil groups on the eastern side of a land mass and north of the equator. (*Modified from C. E. Kellogg and the Yearbook of Agriculture, 1941.*)

because of the lack of abundant soil moisture and are characterized by a considerable, and in some places excessive, content of soluble mineral matter. The process by which they are formed is called calcification. Although there are some significant differences between the soils of the warm dry regions and those of the cool dry regions they are not so marked as are those between the laterites and the podzols in the humid regions. Instead, there is a greater difference between the soils of the very arid or desert regions and those of the subhumid grassland regions, whether they lie in low latitudes or farther poleward. The typical mature soil of a desert region is gray in color, high in saline or alkaline minerals, and low in organic matter, while that of the subhumid grassland region is neutral or moderately alkaline, black or dark brown in color, and high in organic matter. The desert and grassland soils are zonal also, but mainly with respect to the moisture supply rather than to temperature.

To introduce the discussion of the climates of the world the several types were shown on a hypothetical continent (Fig. 82) in order to clarify their typical positions and arrangements. In the same manner Fig. 342 is intended to show the positions and geographical relationships of the great zonal soil groups on a land mass having a situation somewhat like that of North America, extending westward to the Cascade and Sierra Nevada Mountains. These relative positions are repeated, in a general way, in eastern and central Asia, but their order of arrangement is reversed in Europe and western Asia for obvious climatic reasons.

A brief survey may now be made of each of several great zonal soil groups of the world with respect to its profile characteristics and its inherent capacity for human use. Attention may be directed also to the major features of the world distribution of the great soil groups, of which a generalized view is presented graphically in Plate VII. The fact that this map of the world distribution of soil groups leaves much to be desired is due to several conditions: (*a*) Soil types, like climatic types, do not ordinarily change abruptly from one to another but by continuous gradation, and their boundary lines on maps really are drawn through zones of transition. (*b*) The small scale of this map requires that it be very general, but the facts of soil distribution are highly detailed. (*c*) Large areas of some of the conti-

nents are incompletely surveyed as to soil, and information about them is inadequate or almost entirely lacking. (*d*) Writers in describing the soils of other lands have not always done so in the terms employed in the present classification, or they have used the same terms but with different meanings. Attempts to harmonize such descriptions have not been attended by uniformly satisfactory results.

Soils of the Humid Forest Lands

It was noted above that the mature soils of the humid forest lands are of two extreme groups, with several of intermediate character. These may be considered in the following order: (*a*) the lateritic soils, found generally in regions of tropical rainforest climate or the humid subtropics; (*b*) the podzols, which are found principally in the regions of subarctic coniferous forest; and (*c*) the gray-brown podzolic forest soils, which are found in the broadleaf forest regions, intermediate between the other two (Plates VI and VII).

633. Tropical and Subtropical Red and Yellow Soils. Although mature soils in the regions of warm and humid climates are developed largely by the lateritic decomposition of rocks, it does not follow that they are all alike. In fact they are of great variety; since the original rocks differ greatly, there are various degrees of laterization, and some of the lateritic materials have been more or less podzolized. Within the general regions of the humid tropics and subtropics also, there are numerous types of intrazonal or azonal soils. The resulting association of types is so complex that no attempt will be made to distinguish them in the soils map of the world (Plate VII). However, the outstanding characteristics of some of them may be noted briefly, particularly as they may be related to use of the land for agricultural crops.

634. *Lateritic Red Soils.* Soils so highly laterized as to be true laterites (L. *later*, brick) are not widespread. They seem to reach their highest development in the well-drained uplands of regions having the savanna type of rainfall regime In general the laterites are granular, porous, and have low water-holding capacity. They are capable of being tilled immediately after heavy rains but are subject to drought. Being highly leached, they are low in plant foods, both mineral and organic, and are not capable of sustained cropping without heavy fertilization. And, since they are porous, they require irrigation in dry seasons. Most of them have red or brown A horizons and deep B horizons of dark red color. Such as are weathered from rocks high in iron are composed largely of iron oxide, and some are suitable for use as iron ore. In certain localities the original rocks were high in feldspars and low in iron-containing minerals. The lower horizons of the laterites derived from them are buff or gray in color and consist largely of the hydrous oxides of aluminum. Some are so rich in aluminum that they are used as ores of that metal.

It seems remarkable that some soils of lateritic type should, in their natural state, be able to support such abundant vegetation as tropical rainforest and yet decline in productivity so rapidly upon cultivation. It may be that this results from the interrelation between forest and soil. Although the soils are deeply weathered, the roots of the broadleaf trees of the rainforest continuously bring to the surface at least small amounts of the critical mineral elements from underlying sources. This process makes up in some degree for the lack of needed minerals in the leached surface horizons. When the forest trees die and decay, the minerals and some of the organic material contained in them are returned to the surface soils and are in part reabsorbed by the roots of other trees, thus providing a sufficient supply as long as the forest exists. Following the destruction of the forest and the planting of shallow-rooted crops, this cyclic movement of minerals and organic nutrients is interrupted, and the surface reserves are quickly depleted. Moreover, removal of the forest and the tillage of crops hastens erosion and the removal of the surface soil with its meager store of both mineral and organic plant foods. It may also hasten the leaching process by permitting the rapid downward movement through the porous lateritic

subsoil of that part of the soil water which would have been absorbed by the roots of the forest trees and transpired in great quantity through their leaves.[1]

Soils of the lateritic type are not well suited to crops such as corn or tobacco that draw heavily on soil fertility. They are better adapted to the growth of crops such as oil palms which utilize the intense tropical sunlight and abundant rains for the production and storage of fats, starches, sugar, and other carbohydrates.

635. *The Red and Yellow Soils: Lateritic and Podzolic.* Far more extensive in area than the laterities, and of much greater agricultural importance, are related types which may be called the *lateritic and podzolic red and yellow soils.* Not only are they found in the rainy forest lands of the tropics, but they are also widespread in the humid subtropics, such as the Cotton Belt of the United States and southern China (Plate VII). They have been subjected to the process of laterization, but either the process has not been so complete as in the case of the laterites, or it has taken place under slightly different conditions of rainfall and drainage. The upper horizons of these soils generally are brown, friable clays and loams. The B horizons usually are deep and more compact than in the laterites, and their colors vary from red to yellow or mottled. The lighter colors result from a less complete oxidation of the iron content, and this in turn is believed to indicate more abundant soil moisture resulting from either greater rainfall or less thorough underdrainage. Many of the red and yellow soils have been more or less affected by podzolic processes, especially such soils as are derived from sandy materials and are porous, as in the Atlantic Coastal Plain of the United States. In such soils, a thin upper layer of organic material is underlain by a leached gray or yellow A horizon, and this in turn is underlain by an acid B horizon of red or yellow lateritic material.

The agricultural capacity of the mature red and yellow soils is distinctly better than that of the laterites. Although, as a class, they are low in readily available lime and other alkaline substances, they still contain some reserves of unweathered rock minerals and considerable colloidal materials from which these plant foods may be made available. Their generally finer textures cause them to be more retentive of moisture, but permit adequate drainage. However, their supplies of organic matter seldom are abundant. Under cultivation the colors of the red and yellow subsoils usually predominate. That is because cropping quickly uses the small surface reserve of organic matter, plowing tends to intermingle the A and B horizons, and the higher clay content of these soils makes them more subject to erosion than are the laterites. Although they presently become exhausted under continuous cropping, they respond well to fertilizers because of their fine textures. In some regions they are kept in continuous productivity by heavy fertilization, but in others worn-out lands are abandoned for periods of years to permit the accumulation of new reserves of plant food.

636. Soils Associated with the Red and Yellow Soils. It was noted previously that mature soils of the lateritic red type, like other mature soils, attain their best development upon undulating surfaces where underdrainage is free and erosion is small but not entirely absent. From that it may be inferred that there are many localities, within the large areas shown as lateritic soils on Plate VII, that do not have mature soils of that type. The soils of some of these are intrazonal, and those of others are azonal in character. Among the former are the soils of boglands or other areas of poor drainage and such as have an unusual lime content, owing to the limy nature of their parent materials. The azonal types include the rapidly eroding surfaces of steep slopes, where the soils are thin, stony, and immature. They also include porous sands without profile development, recent deposits of volcanic ash, and especially the recent alluvial deposits of floodplains and deltas. In these latter the rate of accumulation is too rapid to permit of the slow development

[1] Felix Rawitscher. Die Erschöpfung tropischer Böden infolge der Entwaldung. *Acta Tropica*, Vol. 3, pp. 211–241, 1946.

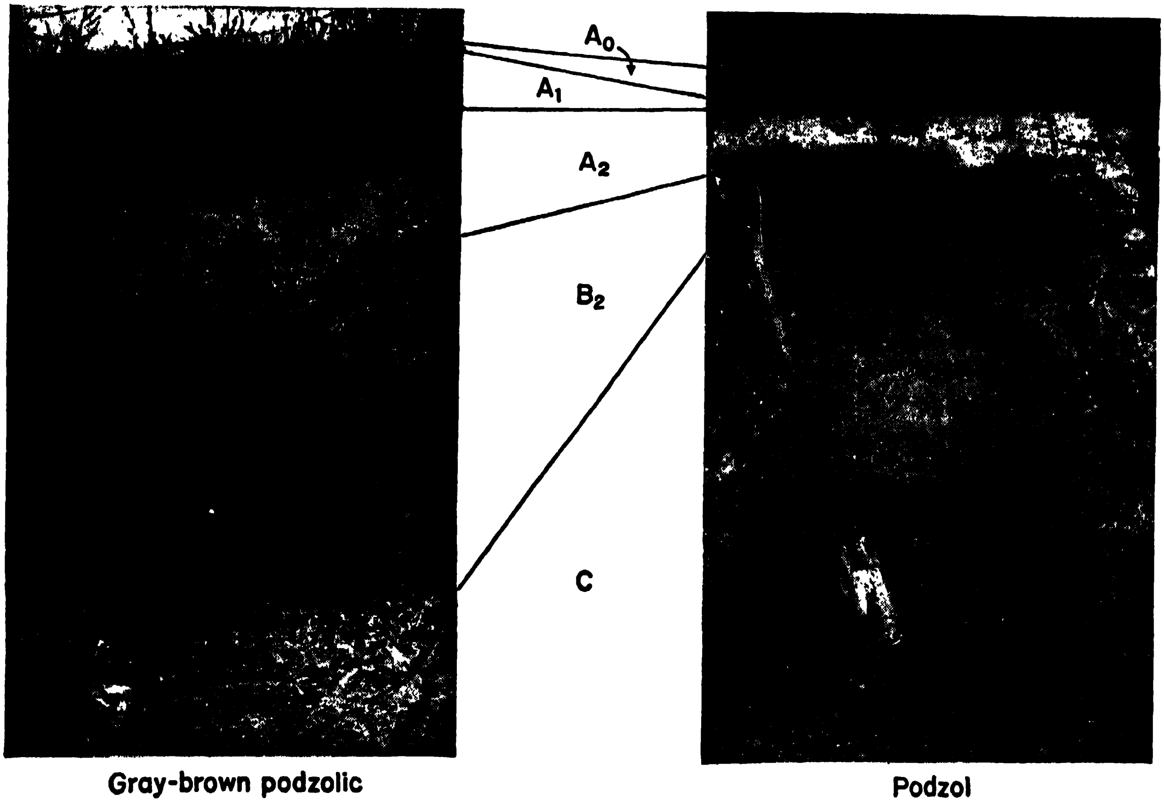


Fig. 343. These photographs show contrasts in thickness and color of the several horizons common to the podzols and the gray-brown podzolic soils of Ontario. (*Photographs by G. A. Hills, Ontario Department of Lands and Forests.*)

of the normal profile. Yet in most instances they are, where adequately drained, more productive agricultural lands than the mature soils with which they are associated. Henceforth it will be understood that the intrazonal and azonal soils exist in association with each of the great soil groups to be discussed, and particular reference to their characteristics will be brief.

637. Podzols. Podzols are the typical mature soils of regions having humid subarctic climate (Plate VII). Although it occurs in the humid tropics and subtropics, podzolization is much more favored by long winters and short summers. Podzolic soils are different from lateritic soils in structure, profile, and color.

The mature podzol is developed under a natural vegetation of forest, but in this case it is mainly coniferous forest. Conifers do not require abundant basic soil elements for their growth, and since they are mainly shallow-rooted trees, they draw only small supplies of the soil bases to the surface, even where such are available in the parent material beneath. Thus, there is little chemical reaction to oppose the tendency toward soil acidity. The effect of long cold winter and moderate summer temperatures and a forest litter of resinous pine needles is to retard bacterial action and to permit the formation of a brown layer of raw humus or half-decomposed organic remains, which represents the accumulation of many years. This spongy material on the forest floor retains water, becomes highly acid as the result of fermentation, and the downward-moving soil solutions are made acid by it. The strong acidity is unfavorable to the existence of earthworms, and they are few. Consequently their customary work of mingling the decaying vegetation with the upper soil layers is not accomplished, and the line of separation between raw surface humus and the mineral soil is sharp. Moreover, the effect of the strongly acid solu-

tions upon the soil minerals is very different from that under the weakly acid or neutral solutions found in tropical soils. The acid solutions render soluble and remove from the surface soil the iron and aluminum, which, under tropical conditions, are oxidized and left at the surface. Underneath the layer of raw humus the A horizon of a mature podzol is leached of its iron and readily soluble minerals, and by eluviation, it has lost most of its clay and colloidal constituents also. It is, therefore, poor in the mineral elements of soil fertility and nearly structureless. Through loss of iron it is bleached to a grayish-white color (the name podzol is derived from Russian words meaning "ashes underneath") (Figs. 341 and 343). Beneath a bleached A horizon of variable thickness there is typically a brown, acid B horizon which is strongly illuviated. In it are deposited some quantities of the iron and other minerals leached from above and even part of the finely divided or colloidal clays and organic material which have passed through the A horizon. In some localities these substances bind together the mineral particles of the B horizon, cementing it into a stony layer, or *hardpan*. The C horizon is composed of the glacial drift or other parent material of the soil (Fig. 344). Acid podzols, without improvement, are poor soils for most farm crops. Under cultivation, the surface layer of organic matter soon is lost, and the grayish surface soil requires lime, fertilizer, and good management to keep it productive and to prevent its poor structure from becoming a hindrance to tillage. Although a few food plants, such as the blueberry, grow wild on light sandy podzols, the podzols used for general agriculture are of finer texture. On such soils, after fertilization, potatoes are widely grown. They are acid tolerant. Good yields of grass, oats, rye, and numerous vegetables are obtained from podzols after lime and fertilizers are applied.

Apparently, not all gray forest soils having the general appearance of podzols are acid. Studies in northwestern Canada have shown

Fig. 344. A forest podzol, newly cleared, east of Peace River, Alberta. The plow has turned under the surface layers and has exposed the fluffy whitish-gray material of the lower A horizon (see Figs. 341 and 343).

that in areas of low rainfall the light forest vegetation of the taiga uplands is not coniferous but dominantly aspen. In such areas the soils are gray but not acid. They are neutral or mildly alkaline and in some localities even have a horizon of lime accumulation (641). These soils could perhaps be made agriculturally productive if the summers were longer and more moisture were available.[1]

The main regions of podzol development, as is shown in Plate VII, are in the higher middle latitudes. However, they are not strictly confined to those latitudes. Partially podzolized soils are abundant in the humid lower middle latitudes and are to some extent found in the red-soil regions or even in the humid tropics where unusual conditions have permitted the accumulation of coverings of acid organic matter.

638. Soils Associated with the Mature Podzols. In connection with the podzols, as with the other groups, there are soils of immature or imperfectly developed profiles. Recent alluvial deposits, ice-scoured and steam-eroded slopes, glacial marshes and other areas of high water table comprise large total areas of structureless soils or such as have abnormal or immature podzolic profiles. Podzolization proceeds most rapidly and extends deepest on light permeable materials that are low in lime, such as sand. However, there are, in the region of the podzols, considerable areas of tight glaciolacustrine clays, such as those of the Ontario Clay Belt (449). In some of these the compactness of the clay has impeded the underdrainage, creating wet lands or even muskeg. Over large areas the soils are peaty clays or peat up to several feet in thickness.[2] Peat alone is not good agricultural soil, and it is sometimes removed by burning. Some peat or other organic matter is required, however, for incorporation with the compact underlying clays in order to make them penetrable by water, air, and plant roots and to encourage the activities of earthworms. These wet soils constitute one type of intrazonal soil associated with the true podzols. Some other intrazonal soils are better for general agriculture, requiring less expensive improvement. Not even the normal well-drained soils of the region, however, are equally podzolized. They have developed under different kinds of natural vegetation which have grown in response to differences in slope, exposure to sunlight, or the nature of the underlying rock. These differences tend to modify the nature of the soil profile or to retard its full development. However, it is probable that among the many somewhat different soils of the podzolic soil regions there is a degree of unity in characteristics which is sufficient to set them well apart in appearance and utility from the soils of the other major groups.

639. The gray-brown forest soils are the typical mature soils of those regions of the world that have broadleaf deciduous forests and humid microthermal climates (Plate VII). They are podzolic soils but not fully developed podzols. They may be considered as intermediate in characteristics between the podzols and the subtropical red and yellow soils. They also reach their normal development under forest vegetation but mainly under deciduous forest with associated shrubs and grasses. Under these vegetational and climatic conditions there is a surface accumulation of organic material which forms a dark layer 1 to 3 in. deep. It is less rapidly decomposed and typically more abundant than the organic accumulations associated with the tropical red soils, but it is not so abundant, so poorly decomposed, or so acid as that associated with the podzols. Moreover, the organic material derived from broadleaf forest contains more lime, potash, and other basic elements than does that from coniferous forest, and these are easily mixed with the mineral components of the soil. The A horizon of the podzolic gray-brown forest soil is leached but not impoverished or greatly bleached. It generally is stained with iron but by a brown hydroxide of iron rather than by the red oxide common in the tropics. The admixture of

[1] Marie Sanderson. Drought in the Canadian Northwest. *Geog. Rev.*, Vol. 38, pp. 289–299, 1948.

[2] G. A. Hills. "Pedology, The Dirt Science, and Agricultural Settlement in Ontario." Pp. 18 and 20. Ontario Department of Lands and Forests, Toronto.

organic matter to the brown surface material gives the grayish-brown color from which the group name is derived. The quantity of organic material decreases downward, and the B horizon is yellowish brown and of heavier texture than the A horizon, because it has been illuviated from above. As in the podzols, the C horizon is the little-changed parent material of the soil, much of it glacial drift. The gray-brown soils have generally better structures than the other forest-land soils, keep their structures better under cultivation, and respond more readily to the application of lime and organic fertilizers. The humus of forest origin is better distributed in the upper gray-brown soil horizons than in the podzols, because of the work of earthworms and other soil organisms which thrive under the less acid conditions. This reserve of humus, together with some quantities of the critical soil minerals, causes newly cleared gray-brown soils to be productive. However, they presently lose their strength under continuous cropping unless they are carefully managed and well fertilized.

Plate VII shows the mature gray-brown podzolic soils to be typical of some of the intensively cultivated agricultural lands of the world, such as northeastern United States, northwestern Europe, and several other regions of smaller size. The North American region is a large and important one. It includes much of that area originally covered by mixed hardwood forests, and it extends from Maryland and southern New England westward to southern Wisconsin and southern Illinois. This is the most densely populated part of the continent. It is also an area of great agricultural diversity. Indeed, one of the distinctive characteristics of the gray-brown podzolic soils is their suitability to a wide variety of crops: hay and pasture, small grains and corn, vegetables, root crops, and many others. This great soil group includes soil families, series, types, and phases in great number and of complex distributional patterns. They are derived from many kinds of parent materials: rocks of many classes, the several types of glacial and glaciofluvial deposits and others on the nearly level glacial plains. From most of them the once extensive forest has been removed to make place for farms, and erosion has set in. It is in this area of local differentiation of soils resulting from differences in slope and drainage that the idea of the soil "catena" (627) has gained special recognition.

640. Soils Associated with the Mature Gray-brown Forest Soils. Included in the areal patchwork made by the various series and types of the normal gray-brown podzolic soils are others which are not zonal. Among these are such azonal soils as fertile river alluvium and infertile sands and gravels, the latter resulting from sandy glacial outwash or from the abandoned shore deposits of temporary glacial lakes, etc. Even more widespread are types of intrazonal soils that have resulted from poor drainage. Among these are dark-colored soils formed in the swales of till plains or in other marshy or boggy places. In them the surface soils are high in organic matter derived from the remains of grasses, sedges, and other marsh plants. They commonly are underlain by sticky compact clays. If drained, these soils are productive. Also included, and often in larger areas, are the soils of extensive drift-covered glacial uplands so flat that, under their natural vegetation of forest, little erosion took place for centuries. In them the soil-making processes and poor drainage have resulted in the formation of a leached and acid A horizon underlain by an impervious B horizon. The capacity of these soils for producing crops varies greatly with local conditions, but generally it is less good than that of the zonal soils with which they are associated.

Soils of the Subhumid Grasslands and Deserts

It was previously indicated that the soils of the subhumid grasslands and the deserts are to be distinguished from those of the humid forest lands. It was noted also that a clear distinction is to be made between the dark-colored grassland soils and the gray soils of the deserts. These groups may be considered in the order just stated.

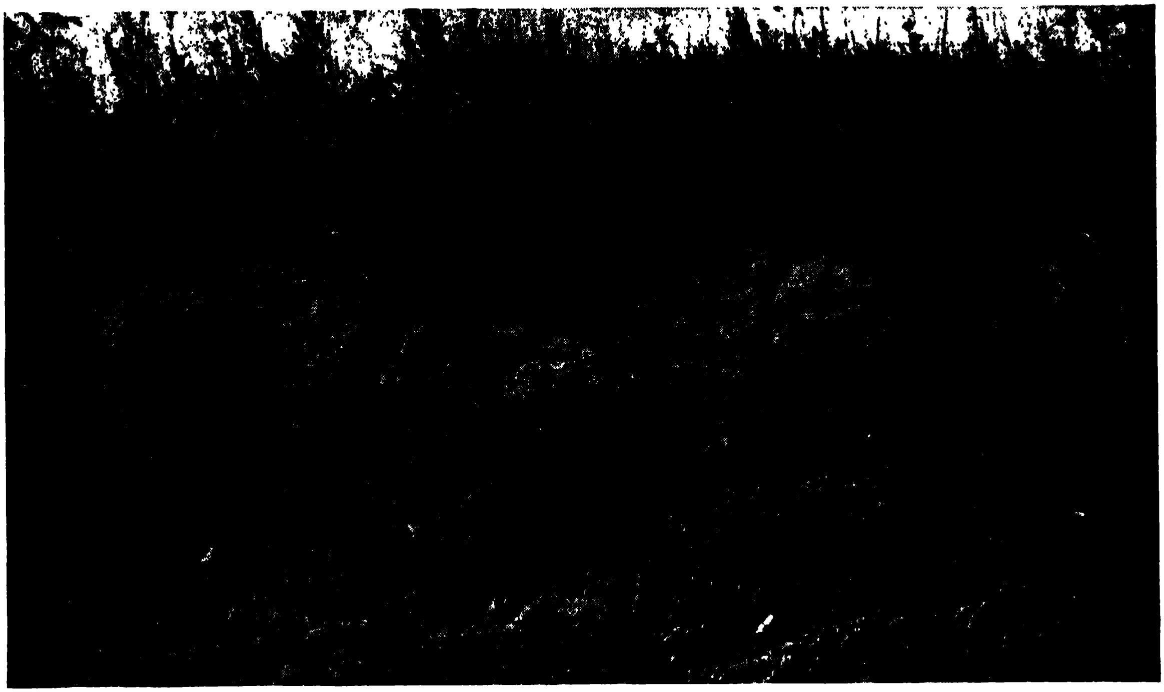


Fig. 345. A vertical section in a mellow grassland soil of the chernozem type near Hythe, Alberta. The deep penetration of grass roots is shown clearly (see Fig. 341). (*Photograph by Mary McRae Colby.*)

641. The Dark-colored Grassland Soils. Forest ceases to be the dominant vegetation in both tropical and middle-latitude climates where dryness, as it is expressed in terms of precipitation, its distribution, absorption, and evaporation, reduces the supply of soil moisture below a critical amount. The amount of moisture required to support a forest varies with latitude, altitude, and other conditions, and it is not possible to draw a clearly defined climatic line that will everywhere coincide with the boundaries between forest lands and grasslands or with the soil boundaries associated with them.[1] However, the result of increasing dryness is that, eventually, forest ends and grass becomes the dominant vegetation. The effect of limited soil moisture, and the presence of grass cover, is to cause the development of soils very different from those of the humid forest lands.

In regions where the moisture supply is almost, but not quite, sufficient to support a forest vegetation, it normally is sufficient to support a dense and luxuriant growth of grasses. The growth and annual death of a part of the thick grass sod and its fibrous roots add organic matter *in* the soil where it decomposes slowly and gives rise to a large supply of humus. However, the accumulation takes place under conditions of moderate to low moisture supply, and the humus is not prevailingly saturated, and it is not acid. Because the humus is largely of grass-root origin, it is not confined to the surface but extends to depths of several inches to 3 or 4 ft. Slow leaching leaves sufficient lime to combine with the large amount of organic colloids and colloidal clays in these dark soils, thus promoting excellent structural conditions, which are found in all the soil horizons (Fig. 345). The abundant and deep organic material also is the source of much of the agricultural strength for which these soils are famed and of their prevailing dark colors. Owing to the deep penetration of the organic material, the horizons of the grassland soils usually are not so sharply defined as are those of the forest soils, and they change only gradually to a parent material beneath.

Because the grassland soils develop under comparative dryness, they are less leached than

[1] See Art. 581 and footnote.

any of the soils previously considered. There is normally a redistribution in the soil profile of the lime contained in the parent material, without a complete removal of it. In fact there is in most of these soils *a horizon of lime accumulation* which is one of the characteristics distinguishing the soils of the dry lands from those of the humid climates. Frequent periods of drought cause upward movements of capillary water. This movement brings up lime, dissolved from the parent material of the soil, and the evaporation of water from the soil surface causes its deposition. Subsequent rains tend to carry the lime down again, but ultimately a position of balance is established. The position of that horizon depends upon the supply of soil moisture and the quantity of lime in the parent material. It is nearer the surface in regions of abundant lime and low rainfall and farther down in soils that are better supplied with moisture or are derived from parent materials poor in lime (Robinson).

Since dark soils of the general group here described are found over large areas of subhumid climate, both in middle latitudes and in the tropics, it is not to be supposed that all of them are alike. They differ as a consequence of (*a*) amount and seasonal distribution of precipitation, (*b*) conditions of temperature, and (*c*) the types of grass vegetation under which they have developed. Only three major subdivisions of the grassland group may be noted in greater detail.

642. *Prairie Soils.* Adjacent to some of the forest-soil regions, but on their drier margins, are very dark brown prairie soils that may be thought of as intermediate in type between the true steppe soils and the forest soils. These intermediate soils, which may be called *prairie soils*, are widely developed in the United States, Russia, and South America, and there are others somewhat like them in Africa. They appear to have formed under a natural vegetation of tall grasses but in climates having sufficient moisture so that the land might have supported forests. The reason why there were not forests in these regions is not clearly understood (599).

The prairie soils are like the steppe soils in their fine granular textures and dark color. Both these qualities are derived from abundant and deep accumulations of the organic matter of grass roots. They are different from them and like the podzolic forest soils, in that they are low in lime and other alkaline substances. They have no horizon of lime accumulation but are only weakly acid. This condition is due to the fact that they are supplied with sufficient moisture so that there is a predominant downward movement of the soil solutions that carry the readily soluble minerals below the lower limits of the soil profile and into the underground water circulation. The prairie soils are, however, excellent agricultural soils. Because of their high humus content, their good structure, and the more abundant soil moisture associated with them they are among the most productive soils of the world. Like the chernozems and steppe soils, they produce excellent grain crops, and like the gray-brown forest soils, they are adapted to a great variety of other farm crops.

The rich corn-belt soils of central Illinois, Iowa, and Missouri are prairie soils (Plate VII). The typical mature soil is found on rolling interfluves where the natural vegetation of prairie grasses was best established. In the United States they are developed mainly in regions of older glacial drift on which are considerable admixtures of loess. On steeper slopes, especially river bluffs, fingers of woodland originally projected into the prairies. On such sites the gray-brown podzolic soils were developed.

Somewhat like the prairie soils, and included with them in the map (Plate VII), are some that appear to have passed the climax of their development and to have entered a stage of retrogression. They are called "degraded chernozems" (643). It appears that they developed originally as black steppe soils and were lime accumulating, but owing to increased rainfall or other possible changes, they have lost much of their lime and have been more or less invaded by forest vegetation. Podzolization has set in, and the subsoil has become lighter. Still, however, the surface soil maintains the dark color

and high productivity inherited from its earlier condition. Degraded chernozems are recognized especially in Russia.

In several humid regions there is another kind of dark-colored soil, high in humus, which is found in association with the red and yellow soils, the gray-brown forest soils, and perhaps others. It is similar to prairie soil in character and yet significantly different in origin. The soil type is called *rendzina*. It is developed from parent material containing lime in such abundance that the supply continues to exceed the rate of loss through leaching. Hard limestones break down too slowly to form rendzinas. In soft chalky limestones, however, or in beds of glacial or lacustrine marl, the rate of physical disintegration is more rapid than the rate at which leaching can remove the lime. Consequently, the resulting soils are high in lime in spite of heavy leaching. High lime content encouraged an original vegetation of tall prairie grasses rather than forest. This, in turn, produced a dark soil of the prairie-soil type, with which they are grouped in Plate VII. Examples of rendzinas are found in the soils of the Black Prairies of Alabama and Texas, in certain dark soils of eastern Cuba, in some of the chalk lands and glacial marls of Europe, and elsewhere. Many of the areas are too small to be shown individually in Plate VII, and they are included with adjacent soils.

643. *Chernozem Soils.* Chernozem (a Russian word meaning black earth) is the name applied to a type of soil that is naturally the most fertile, although perhaps not the most adaptable, of the grassland-soil group. It is formed under a dense vegetation of prairie and steppe grasses and under average annual precipitation sufficiently low (about 20 in. in the United States) so that, while the most soluble soil minerals are leached out, an abundance of lime and the less soluble alkaline minerals remain. The low precipitation also results in a lack of eluviation, and the soil has a large component of clay and colloids. In true chernozem soils the horizon of lime accumulation lies generally between 3 and 5 ft. beneath the surface and is still within reach of the grass roots, which find in it an inexhaustible source of calcium. The surface material of the chernozem is high in humus and of a black or very dark-brown color (Fig. 341). The soil structure is well flocculated, granular, and porous. Upon tillage it crumbles into a fine seedbed, and it has a large capacity for holding water. The reserves of both organic and mineral plant food in chernozems are so abundant that the soils will stand cropping for long periods without fertilization. The high colloidal content of chernozems causes them to be extremely plastic and sticky when they are wet and, on slopes, to suffer badly from surface erosion when they are cultivated. In general, however, there are no better soils than chernozems for grain, cotton, and other extensive field crops that draw heavily upon soil fertility.

Plate VII shows the probable world distribution of the chernozems. These highly fertile soils reach their most excellent development in the middle latitudes, especially on the gently undulating uplands along the prairie-steppe margin of the United States and in southern Russia. However, even in North America there are differences between the chernozem of the northern end of the belt, in Canada and the Dakotas, and that of Texas. The latter was developed under grass and shrub vegetation less dense than the northern sod and under higher temperatures. It has, in consequence, a lower humus content and a more brownish-black color and a redder subsoil.

In regions of subhumid tropical grassland also there are belts of dark soils which are classed as chernozem. They are shown in Plate VII. These soils have not been studied so widely as the chernozems of higher latitudes, but they appear to be like the latter in that they contain abundant organic matter and a horizon of lime accumulation. However, long-continued high temperatures hasten the decomposition of organic matter, even under subhumid conditions. It is probable that a large part of the tropical chernozems are neither so deep nor so black as those of the Dakotas. They are apparently more like those of Texas. Also, according to Shantz and Marbut, those of Africa at least are notably heavier in texture and more difficult

to cultivate than similar soils in America. The black soils of central India, classed with the chernozems in Plate VII, are derived from the weathering of basic igneous rocks, and they owe their black color to their peculiar mineral content rather than to abundant organic matter.

644. *Brown Steppe Soils.* Adjacent to the chernozems, but on their drier margins, are soils which, although similar, show the effects of a decreased moisture supply. The line of separation seldom is sharp, and the transition from the black soils commonly passes through soils of chestnut-brown to those of reddish-brown color. These together may be called the *brown steppe soils* (Plate VII), and they are to be clearly distinguished from the podzolic gray-brown forest soils.

The brown steppe soils show the influence of decreased moisture in several ways. First, it may be noted that they have developed under a grass cover less luxuriant and deep rooted than that associated with the chernozems and the prairie soils. In general, it is a continuous sod cover of various species of "short grass," but it includes also areas of grass with intermingled desert shrub. The roots of the grasses provide an abundant but less penetrating source of humus than those of the tall grasses. The dryness of the earth has promoted the formation of brown rather than black humus, which is intermingled with a powdery surface soil and lies above a subsoil of somewhat coarser and more lumpy structure than that of the chernozems. The brown steppe soils have, like the chernozems, a zone of accumulated lime or other alkaline substances, deposited beneath the surface by the movement of soil moisture. Because the precipitation of the brown steppe-soil regions is slight, the horizon of alkaline accumulation is relatively near the surface (1 to 2 ft.), and in some localities, the lime is so abundant that it forms a tough hardpan layer in the soil. In general, however, the soils are easily tilled and are found upon undulating to rolling land well adapted to cultivation. The fact that the brown steppe-soil regions, the world over, are predominantly regions of livestock grazing rather than of soil cultivation is due to the deficiency of rainfall in them rather than to deficiencies in their soils.

645. Desert Soils. The typical soils of the arid lands of the middle latitudes may be called the gray desert soils, whereas those of the low-latitude deserts generally are tinged with red (Plate VII). They develop under sparse vegetations composed of widely spaced desert shrubs and, therefore, lack the abundant organic matter of the grassland soils. Because they are low in organic matter the lighter colors predominate in these soils, and the reds, browns, yellows, and grays of weathered rock minerals are widely exposed. This characteristic is accentuated by the accumulation of lime and other whitish substances near to, or even upon, the soil surface. The alkaline and saline materials usually are present in such abundance that commonly the surface materials, or those immediately below the surface, are cemented by them into crusts or hardpan layers. Sierozem occupies a position between the brown steppe soils and those of the true deserts, although in its general characteristics and uses it is much like the desert soils. The surface materials are usually of a pale grayish color and grade into a limy horizon at a depth of 1 ft. or less. It is formed under a vegetation consisting mainly of desert plants but with scattered short grass and brush. The desert soils, lacking grass, are characteristically low in nitrogen but have large supplies of soluble minerals. In such soils as are of medium to coarse texture, the concentration of alkaline materials is not generally sufficient to be harmful to plants. In some areas, however, the surface accumulation of salt and alkali is so great that cultivated plants cannot grow in it. This condition, in its extreme form, is found in playa-lake beds (454). It is, however, not only the quantity but also the quality of the salts that determines the agricultural utility of desert soils. It is commonly held that soils in which the compounds of calcium predominate maintain better structures under irrigation, whereas a predominance of sodium salts tends to destroy the soil structure and eventually to render irrigated land unfit for use.

It is probable that the larger parts of the great deserts are not covered with mature soils. Associated with the latter are patches of rock desert or stream-eroded pediments (453), expanses of desert pavement covered with the varnished pebbles left after wind deflation (457), tracts of dune sand, and areas of immature soil resulting from the recent and rapid growth of alluvial fans. Alluvial soils are the most widely cultivated in arid lands because of their suitability for irrigation. But even desert sands contain so many undecomposed rock fragments that they are well supplied with soluble minerals, and if abundant water is available for irrigation they may be made agriculturally productive.

Soils of the Subpolar Regions

646. Tundra Soils. In the treeless regions of the Arctic fringe the prevailing soil characteristics are not those of the steppe or desert. The soil profile shows evidence of excessive rather than deficient moisture. This is due to the low rate of surface evaporation and to the presence of permanently frozen subsoil at a depth of about 3 ft. The better drained sites of the Arctic-fringe regions have soils somewhat like podzols, but the usual horizons include a brown peaty surface layer which is underlain by grayish horizons, one of them characteristically plastic or even fluid. A large part of the tundra is poorly drained and the prevailing soil conditions are those of bog and hummocky marshland. The soils are in several respects similar to the glacial marsh and bog soils found in middle latitudes, many of which are drained and cultivated. In the Arctic region large areas cannot be drained, are unsuited to tillage, and support a natural vegetation useful only as pasture. Better drained slopes and those most exposed to sunlight offer possibilities for the growth of a few short-season agricultural crops.

Soil Conservation

647. Destructive Soil Erosion. There has been already abundant opportunity to observe that erosion is one of the most powerful and widespread of the processes involved in the modification of the earth's surface. The fact that, in the geologic past, soil has been removed during the slow processes of land degradation is not now a matter of great concern. On the other hand, the fact that present erosion is doing the same thing is a matter of vital concern, because human disturbance of the balance of nature has greatly accelerated the process, and it is now removing the upper horizons of developed soils much faster than natural processes can replace them. In some localities soils are fast being removed down to the parent materials of the soil or even to bare rock. This is destructive soil erosion, since there is lost in a few years or in a few generations a resource which has required thousands of years for development, a resource which cannot be replaced.

Not all kinds of soil are equally subject to destructive erosion. It may be appreciated from foregoing descriptions that some soils, such as the true laterites or eluviated sandy soils, might even benefit by the uniform removal of some depth of surface soil. This would expose less weathered minerals and less leached materials underneath. But those soils, because of their high porosity, are among those least subject to rapid erosion. On the other hand, the dark-colored soils, with the organic accumulations of the ages in their upper horizons, are highly subject to erosion, as also are certain of the forest soils of high clay content.

648. Measures of the Destructiveness of Soil Erosion. Some idea of the destructiveness of soil erosion in the United States may be had from a government report[1] which states that the annual losses of plant nutrients from the cropped lands and pastures of the country through leaching and erosion are almost six times greater than the quantity of those elements removed from the same lands in crops or forage. The same report states further as follows:

> Already the utility of 35 million acres of formerly good farm land has been essentially destroyed, in so far as the production of cultivated crops is concerned,

[1] "Report of The National Resources Board." P. 162. U.S. Government Printing Office, Washington, D.C., 1934.

CHAPTER 26: *The Mineral Fuels*

652. World Industry and the Mineral Fuels. Industrial civilization of the modern type is based to a large extent upon the mineral fuels, principally coal and petroleum. It is possible that controlled atomic energy may sometime provide power for certain types of industrial and transportational uses. However, in spite of urgent and continuing experimentation to that end, the time has not yet come when dependence on the mineral fuels can be decreased. Therefore, no full appreciation of the potentialities of regions or countries for human use, or of their industrial development and economic problems, is possible apart from their relation to these fundamental earth resources. For that reason it is essential that the student of geography have a clear understanding of the nature and the principal variations in quality of these substances, the comparative supplies available in the world's greatest deposits, and the major features of their patterns of distribution.

653. The Location of Mineral Fuels Explained through Geological History. Coal and petroleum are parts of the earth's crustal structure and belong to the nonrenewable class of resources. Their origin and present occurrence are explainable only in terms of the processes and events of earth history. When the outlines of these conditions are grasped, it becomes apparent that there are large parts of the world in which it is unreasonable to expect that valuable deposits of these substances ever will be found. It becomes equally clear why it is possible for certain other regions to have large supplies of one or even both of them.

It is desirable that the major geological time relationships of the coal- and petroleum-bearing rocks be grasped quickly when they are referred to later. To promote that understanding, without digression into the realm of historical geology, the general features of the matter are presented graphically in the simplified geological column to which previous reference has been made (Appendix E).

Coal

654. The Structural Associations of Coal. Coal is a form of sedimentary rock the materials of which are derived largely from the unoxidized carbon of plant tissues. Even thin beds of coal represent long periods of accumulation, during which the remains of luxuriant vegetation were preserved from the ordinary processes of complete decay by being buried underneath swamp waters and, subsequently, beneath layers of clay, sand, or lime. The origin of coal, mainly as deposits in ancient swamps, has several points of geographical significance. First, it may be noted that the original position of all swamp deposits is nearly horizontal. That may be observed in modern swamps. When such deposits are buried underneath other sediments, they become members of a series of horizontal sedimentary rocks. The coal beds of some of the greatest coal fields of the world have still an essentially horizontal position, a condition that simplifies the problems of coal mining. In other coal fields the beds are not horizontal but, together with their associated rocks, show evidence of disturbance subsequent to their deposition, through warping, folding, or faulting. In some places this has involved the metamorphism of the coal. A second point of significance is that modern swamps seldom are of vast extent. A

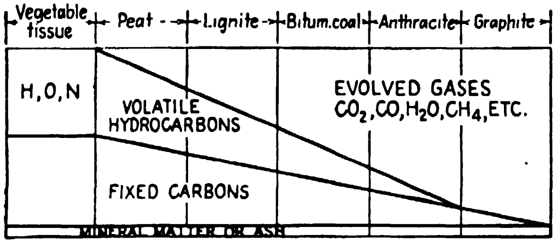


Fig. 350. A diagram to illustrate stages in the slow metamorphosis of vegetable material into coal of various types. (*After Newberry.*)

few, such as those on the Atlantic Coastal Plain (395), contain many square miles or even some hundreds of square miles of area, and it is probable that larger ones have existed in the past. However, it is not surprising, considering their swamp origin, that individual beds of coal are not of great extent. Only a few are of such size that the same bed may be traced underground for many miles. Although most of the individual coal beds are of relatively small areal extent, the same is not necessarily true of the great coal fields. In the regions now occupied by some of the larger fields, general conditions favorable to the growth of luxuriant swamp vegetation and the accumulation of plant remains seem to have existed widely and for long periods of time. In such regions it is probable that individual swamps flourished and disappeared, to be buried at last underneath accumulated earthy sediments while, at the same time, other swamps grew near by. Subsequently, conditions were altered, and another swamp formed above the remains of the older one but separated from it by layers of sediment. All degrees of variations in the circumstances of deposition are recorded in the present formations of some coal fields. Large or small, thick or thin, the beds are widely distributed in area and in vertical sequence. In some localities they so far overlap each other that a mine shaft may pass through two or more thin and unprofitable coal strata among the rock formations before reaching one of desirable thickness and quality. In certain localities a half dozen or more coal beds are known to lie one above another, separated by various thicknesses of sedimentary rock.

Since coal is known to occur within the rocks belonging to a fairly well-defined range of geological time, it is possible, by studying the rock outcrops, to determine the general extent of a coal region and, by means of test borings, to discover the number and relative thickness of the coal beds in its various parts. Upon information gathered in that way, it is possible for geologists to approximate with fair accuracy the quantity of coal available for future use in any given field or in any country or in the world, so far as its rocks have been examined.

655. Varieties of coal differ greatly from region to region, and even within the same field a considerable number of market classes and grades of coal may be produced. Several standard classes are recognized, each of which marks a stage in the evolution of swamp deposits into high-grade coal. Only four of them will be mentioned here.

It may be assumed that all coal began as *peat*, preserved but crumbled and blackened organic remains, similar to that which may be seen underlying present swamps and bogs. The higher forms of coal represent successive stages in a transformation of the peat through the weight of the overlying rocks, through diastrophism, or by any other metamorphic processes that involve compression and the loss of water and volatile gases (Fig. 350). A form of deposit somewhat older and more compact than peat is the crumbly brown coal called *lignite*. Still further changes produced the soft black coals of the general class called *bituminous*. Of bituminous coal there is an almost endless list of slightly different grades and qualities. Important fields, and even different parts of the same field or different beds in the same locality, have their own recognized grades. One highly significant distinction among coals of the bituminous class is based upon suitability for the manufacture of coke of the type required in iron-smelting furnaces. Such grades as are suited to that use are called coking coals. Others are called noncoking, but they may be well suited to use as fuel for the production of power or for heating.

Further compression of coal beds, especially if it was accompanied by warping of the formations together with faulting and sometimes heat-

ing, produced the class of hard coal called *anthracite*. The transformation was accompanied by a great loss of volatile gases and water, and the resulting anthracite is low in gas and high in carbon, which makes it a nearly smokeless fuel (339).

656. Coal Classes and Their Relation to Geologic Age. Since coal is formed mainly by the accumulation of vegetation in land swamps or the swamps of coastal margins, it follows that no coal could be formed until there was abundant land vegetation. It is, therefore, not logical to expect that coal will occur in significant quantity in rocks that belong to those periods of earth history before land plants were abundant. Neither is it reasonable to expect coal deposits in igneous rocks, whether ancient or recent, because of the great heat associated with their origin. The time sequence in which the major additions of plant and animal life were made to the earth are shown in Appendix E. From that table it will be seen that the rocks of all the vast extent of time earlier than the Paleozoic bear no evidence of a land vegetation. The general world distribution of those ancient metamorphic and igneous rocks in which the occurrence of coal is impossible may be seen in Plate IV. Even the early Paleozoic periods seem not to have had vegetations of sufficiently high order of development to produce the bog deposits necessary to the abundant formation of coal. Some unimportant coal beds in association with Devonian rocks are known, but it was not until the Carboniferous period that conditions became suitable for the widespread and abundant growth and accumulation of a coal-forming vegetation.

Among the coal fields of the world are those which represent periods of accumulation dating from the early Carboniferous down to the Tertiary period and, if peat deposits be included, down to the present. In a general way, there may be recognized among the many classes of coal represented in these fields a general order of quality which is highest in the older coals and lowest or poorest in those of more recent origin. This order is not without its notable exceptions, yet the general relationship is logical in view of the fact that time is an important element in the transformation of raw peat into good coal. In certain younger coal formations (Cretaceous and Tertiary) are localities that yield coal of high grade, even some anthracite. Usually they are due to diastrophic changes or to igneous intrusion which have, by pressure, fracturing, or heat, made way for the escape of water or gas or have otherwise hastened the transformation.

It may be observed, therefore, that, in general, those world regions which include coal-bearing rocks of late Paleozoic age (Mississippian, Pennsylvanian, Permian) are most likely to possess coal of high quality and that some large areas of coal in regions of younger rocks yield only lignites. Often it is true also that those coal formations which lie in regions of disturbed rock structures have at least some localities in which the quality of the coal has been improved by the disturbance. Plate IV may be referred to again for the broader aspects of the distribution of the older and the younger sedimentary rocks. Of course, only a small part of the sedimentary rocks of either of those age groups was formed under swamp conditions such that coal beds are included among their strata.

657. The accessibility of coal is, in part, a matter of where the coal beds are located with respect to markets, but here its meaning is restricted to the subject of their structural and situational relations to the earth's surface. In some localities of little disturbed sedimentary rocks coal beds are found so close to the surface that they may be mined in open pits after the removal of only a few feet of overburden (surface earth or rock) (Fig. 351). In others they are so far underground as to be reached only by mine shafts of great depth. In still others, although originally they were deeply buried, the coal beds are now made readily accessible by deep stream dissection which exposes outcrops of coal among the rocks of the valley walls (Figs. 352*A* and 353). In regions of complicated rock structure coal beds, once horizontal but now greatly folded, present various degrees of accessibility. In some such localities erosion exposes parts of coal beds at the surface. In others the same beds are bent downward to great

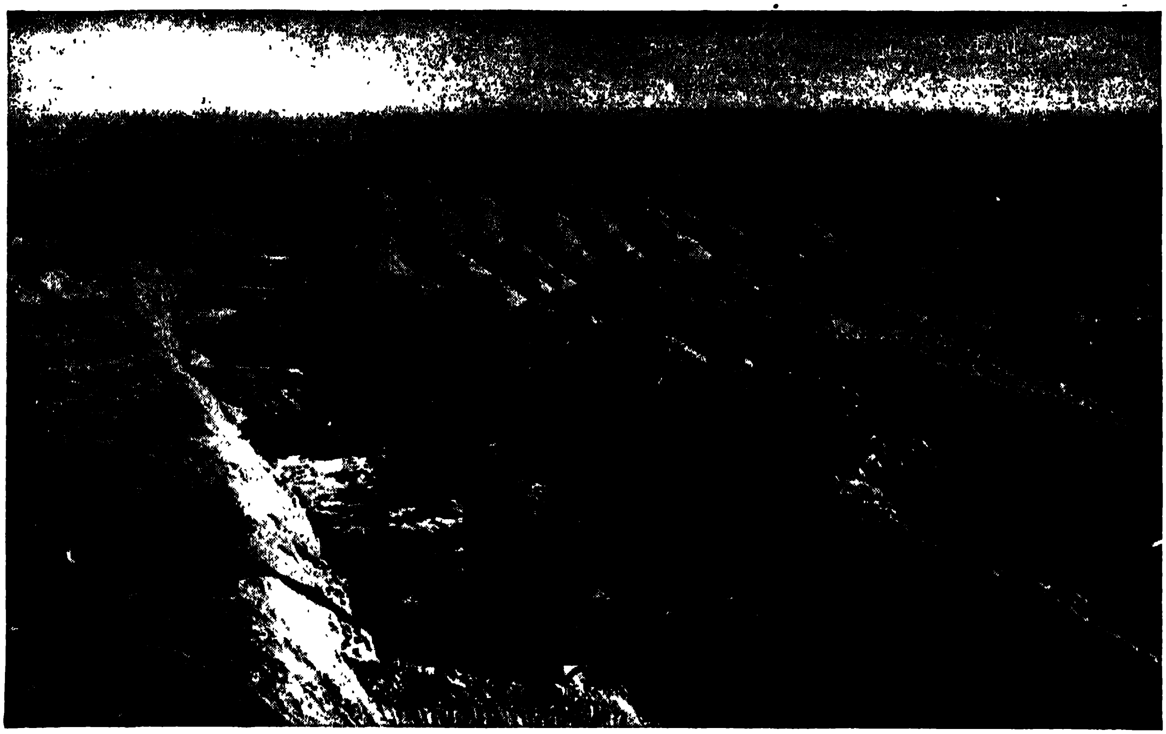


Fig. 351. Giant furrows turned by power shovels in the process of strip mining in southern Illinois. The 4-ft.-thick bed of coal exposed in the bottom of the deep trench is mined out before the next furrow is turned.

Fig. 352. Diagrams to show in contrast the common relationships of surface and structure in the bituminous and anthracite fields of the Appalachian coal regions.

depths or are displaced or shattered by faulting. In such structures the difficulties of mining are greatly increased (Fig. 352*B*).

THE COAL REGIONS OF THE CONTINENTS

658. Because coal still is the principal source of power in manufactural industry and also is necessary for the smelting of iron, its distribution is a matter of critical importance in relation to the world centers of heavy manufacture, present and future. Although there are coal reserves in all the continents and in most of the countries of the world, the distribution of the great ones is most uneven. They are, in fact, grouped in three principal regions: (*a*) central and eastern North America, (*b*) northwestern Europe, and (*c*) eastern Asia. The specific fields of greatest importance in the several continents may now be considered.

659. North America not only is the continent of greatest coal production but also is credited with the greatest of all coal reserves. These have been estimated, including coal of all classes, at 5 trillions of tons, or about two-thirds

of the total estimated supply of the world, although that figure may be somewhat reduced when more complete information is available concerning reputedly large deposits in Siberia. The North American coals include representatives of every class from high-grade anthracite to the lowest grades of lignite. They are contained in several fields, the location and extent of which are shown in Fig. 354.

It will be observed that certain areas of the continent are without coal. Notable among them are the ancient rocks of the Laurentian Shield of Canada and the Appalachian Piedmont and also the young sediments of the Atlantic and Gulf coastal margins. In the complicated structures and partly igneous rocks of Mexico and the regions west of the Rocky Mountains coal fields are small and scattered and, with a few notable exceptions, yield coals of low grade.

660. *The Appalachian Field.* Not the most extensive, but much the most important, among the coal fields of the continent is that of the Appalachian hill region. It is comprised of two principal subdivisions: (*a*) a small highly folded section containing anthracite coal in the Appalachian ridge-and-valley region of northeastern Pennsylvania and (*b*) a large region of little-folded rocks which contain numerous beds of bituminous coal, some of them thick and of high quality. This latter region extends from northwestern Pennsylvania through Ohio, West Virginia, Kentucky, and Tennessee into northwestern Alabama.

The anthracite region is noted for the high carbon and low gas content of its coals and for their smokeless quality. This region is the source of most of the anthracite used in America, but the supply is limited. Moreover, the extreme folding to which the region has been subjected has inclined many of the coal formations at high angles underground, and associated faulting has dislocated them. This has greatly increased the cost and difficulty of mining, rendering anthracite an expensive fuel (Figs. 352*B* and 355).

The Appalachian bituminous region is largely, but not entirely, underlain by workable beds of coal which, in total, represent a period of accumulation which was long, even from the geological viewpoint. Mainly, they are of Carboniferous age and of good quality. Differences in the thick-

Fig. 353. A stratum of bituminous coal outcropping, along with other sedimentary strata, in a road cut on a West Virginia hillside.

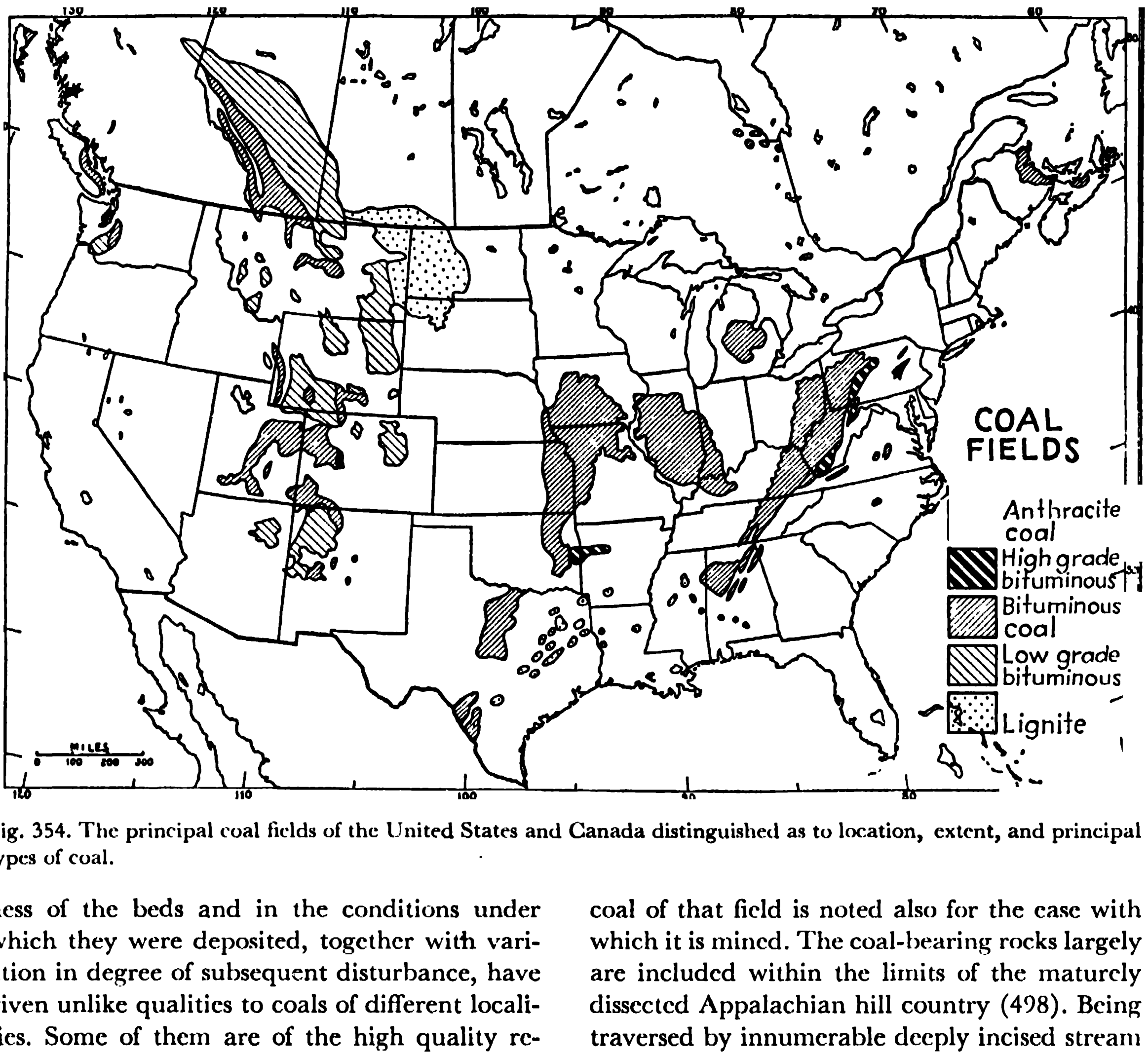


Fig. 354. The principal coal fields of the United States and Canada distinguished as to location, extent, and principal types of coal.

ness of the beds and in the conditions under which they were deposited, together with variation in degree of subsequent disturbance, have given unlike qualities to coals of different localities. Some of them are of the high quality required for the manufacture of blast-furnace coke. That is particularly true of one coal bed of great thickness and large extent in western Pennsylvania. It was the basis of Pittsburgh's early supremacy in iron and steel manufacture, and it still furnishes coke for that and several other smelting centers. Additional supplies of coking coal are now obtained from other sources, especially from fields in West Virginia, Alabama, and other parts of the Appalachian region, but the reserve is not unlimited.

More than three-fourths of the high-grade coal output of the continent, some of which has special uses other than for coking, is obtained from the Appalachian bituminous field. The coal of that field is noted also for the ease with which it is mined. The coal-bearing rocks largely are included within the limits of the maturely dissected Appalachian hill country (498). Being traversed by innumerable deeply incised stream valleys, the coal beds often are exposed along the valley walls, and mining is relatively simple. It is accomplished in large part by means of "drifts," or horizontal tunnels driven into the hillside outcrops of nearly horizontal coal seams (Figs. 352*A*, and 356). In many mines the dip of the coal bed permits the mine workings to slope gently downward toward the mine mouth, and the removal of both coal and drainage waters is aided, or may be wholly accomplished, by gravity. In western Pennsylvania, at least, some of the nearly horizontal coal seams are strip-mined on the hillsides where they outcrop. A power shovel turns a gigantic furrow exposing unweathered coal at the bottom of a trench

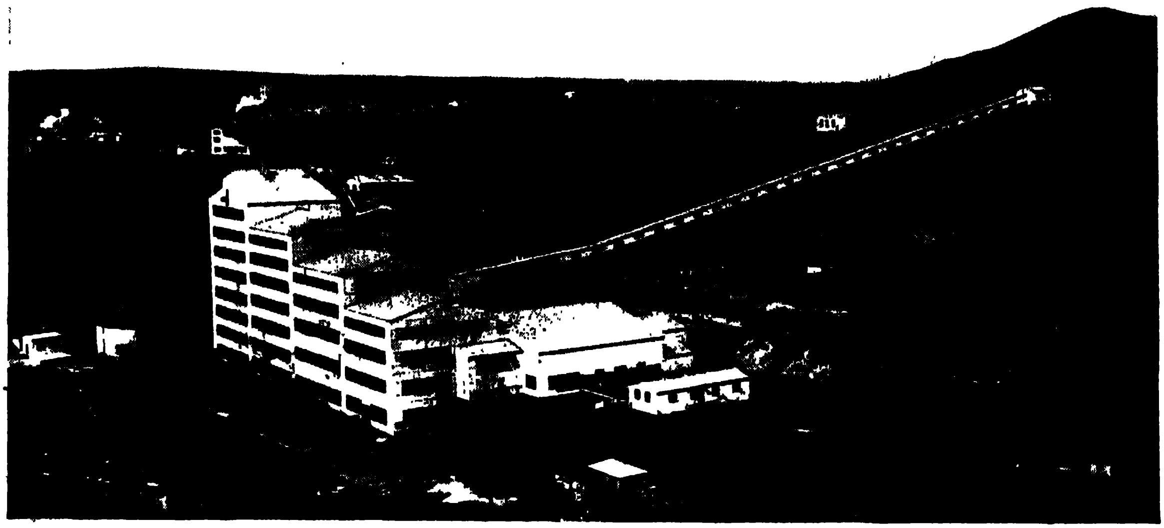


Fig. 355. Some of the pretentious structures associated with the complex underground conditions and deep mines of the Pennsylvania anthracite region. Mountainous piles of waste result from long operation on the same site. (*Photograph by Ewing Galloway.*)

Fig. 356. A small "coal camp" situated in a narrow West Virginia valley. The valley bottom has room for the creek bed, a road, a railroad spur, and two rows of miners' cabins. Simple chutes or "tipples" leading from hillside mines are seen on both sides of the road. Contrast them with the structures shown in Fig. 355.

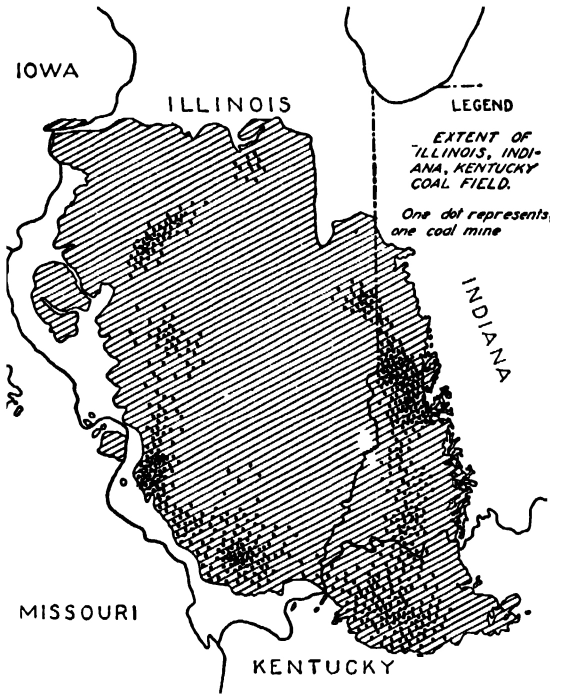


Fig. 357. Most of the coal mines in the synclinal Eastern Interior Field are located upon its more shallow margins.

which follows a contour level more or less around a hill, leaving the more deeply buried part of the seam under the core of the hill to be recovered by future drift mining.

The abundance, accessibility, and high quality of these bituminous coals give the Appalachian fields first importance in America and perhaps in the world. They supply the coal used in the eastern and northeastern industrial districts and also most of the American export coal.

661. *The Interior Bituminous Fields.* The interior region of the United States also is abundantly provided with coal fields. Generally the coal is Carboniferous in age and bituminous in quality. The several areas are known, respectively, as (*a*) the *Eastern Interior Field* (Illinois, Indiana, and Kentucky), (*b*) the *Northern Interior Field* (Michigan), (*c*) the *Western Interior Field* (Iowa, Missouri, Kansas, Oklahoma, and Arkansas), and (*d*) the *Southwestern Interior Field* (Texas). In the Eastern and Northern fields the coal-bearing rocks have broad synclinal structures, and in the former, the coal beds of the middle portion are so deeply buried under younger rocks that they are difficult to reach. Therefore, mining is practiced mainly about the margins of the field (Figs. 357 and 351). In the Western and Southwestern fields the coal beds are inclined gently downward toward the west and pass beneath increasing thicknesses of rock. The coal is mined along the more shallow eastern edges of the fields, where it provides abundant supplies of lower grade bituminous coal for limited local markets.

662. *The Rocky Mountain fields* include many coal districts spread over a large region which extends from the ranges of central Alberta and eastern British Columbia southward to New Mexico. Most of the coal beds of the region are of younger than Carboniferous age. However, there are many localities where rock deformation has improved the quality of the coal, so that the Rocky Mountain province contains coals of greater variety than any other of the American coal regions. Bituminous coal is abundant, and even a small qualtity of anthracite is found. Rocky Mountain coal is important to the region, and some is shipped considerable distances, but the available supply is not generally comparable in quality or quantity with that of the East.

In the Canadian Rockies and underlying the plains of southern Alberta and Saskatchewan is the largest coal reserve of Canada and one of the largest in North America. It contains more than half the coal of the Dominion. Some of that in the mountain area is of excellent quality, but eastward the coal has been less subjected to pressure and is of lower grades. Owing to its far interior situation and limited markets this field is less productive now than a small seaboard field in Nova Scotia.

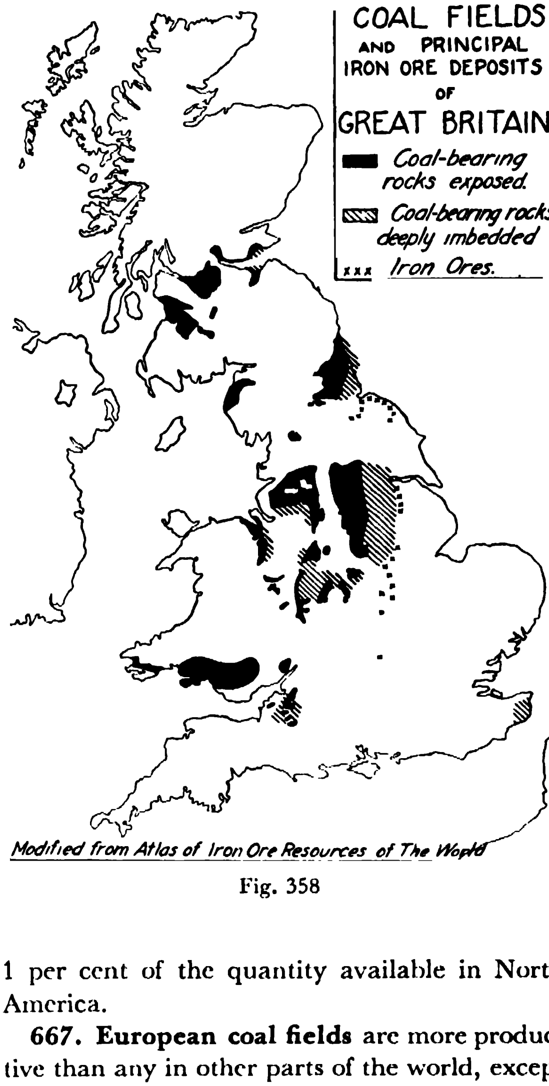
663. *Pacific Coast Fields.* Although much of the Pacific Coast region has no valuable coal deposits, there are a few of considerable local significance. Important among them are those of Alaska, Vancouver Island, and the Puget Sound region. The Alaskan deposits have more future than present value, but those of Vancouver Island especially are important, though limited in quantity, because they are near the

North American terminals of some of the major transpacific steamship routes.

664. *Coal in eastern Canada* is not abundant, because the larger part of eastern Canada is comprised of pre-Paleozoic rocks. Several small inclusions of Carboniferous rocks occur in the Maritime Provinces, and they yield limited quantities of coal. The best and most used deposits, including some coking coal, are found near Sydney on the northern coast of Nova Scotia. These supply a local iron and steel industry, but already they have been exploited until some of the mines extend out beneath the sea and the working of them becomes more and more dangerous and costly. It is a matter of great concern to Canada that its most populous and industrially developed region, which lies between Lake Huron and the city of Quebec, is practically devoid of coal (Fig. 430).

665. *North American Lignites.* In Texas and other Gulf Coast states, in the western interior plains of the United States and Canada, and in the Rocky Mountains are vast areas which are underlain by coals of lower than bituminous quality. Nearly one-half the total coal resource of the United States, and more than three-fourths that of Canada and Newfoundland, are of that class. Mainly it is lignite. The total quantity of these low-grade coals is, therefore, great, but they are not nearly so important as the better coal. Their poor quality involves greater difficulty in storing, shipping, and burning, and they have much lower heat-producing capacity than bituminous coal. They have at present only local use, but they may be used much more by future generations.

666. South America has the misfortune to be, of all the continents, least well endowed with coal. There are in its entire extent only a few areas of coal-bearing rocks. The extensive highlands of the east and northeast are, in large part, of pre-Paleozoic rocks, and the sediments that flank the long eastern front of the Andes are very young. In the Andes of Colombia and Peru and on the coast of central Chile there are small deposits of valuable coal, and there is some of low grade in southern Brazil. Their total reserve is believed to be less than 1 per cent of the quantity available in North America.



Modified from Atlas of Iron Ore Resources of The World

Fig. 358

667. European coal fields are more productive than any in other parts of the world, except those of North America. In total coal reserves Europe ranks third among the continents, and hardly more than one-twentieth of its supply is below bituminous grade. The average quality is, therefore, good. However, it is estimated that the total European coal resource, of bituminous grade or better, is little more than one-half as great as that available in North America, and America has also nearly seventy-five times as much sub-bituminous coal, brown coal, and lignite. The present value of European coal is increased by the fact that the principal fields are so distributed that they fall within the territorial boundaries of several European countries the

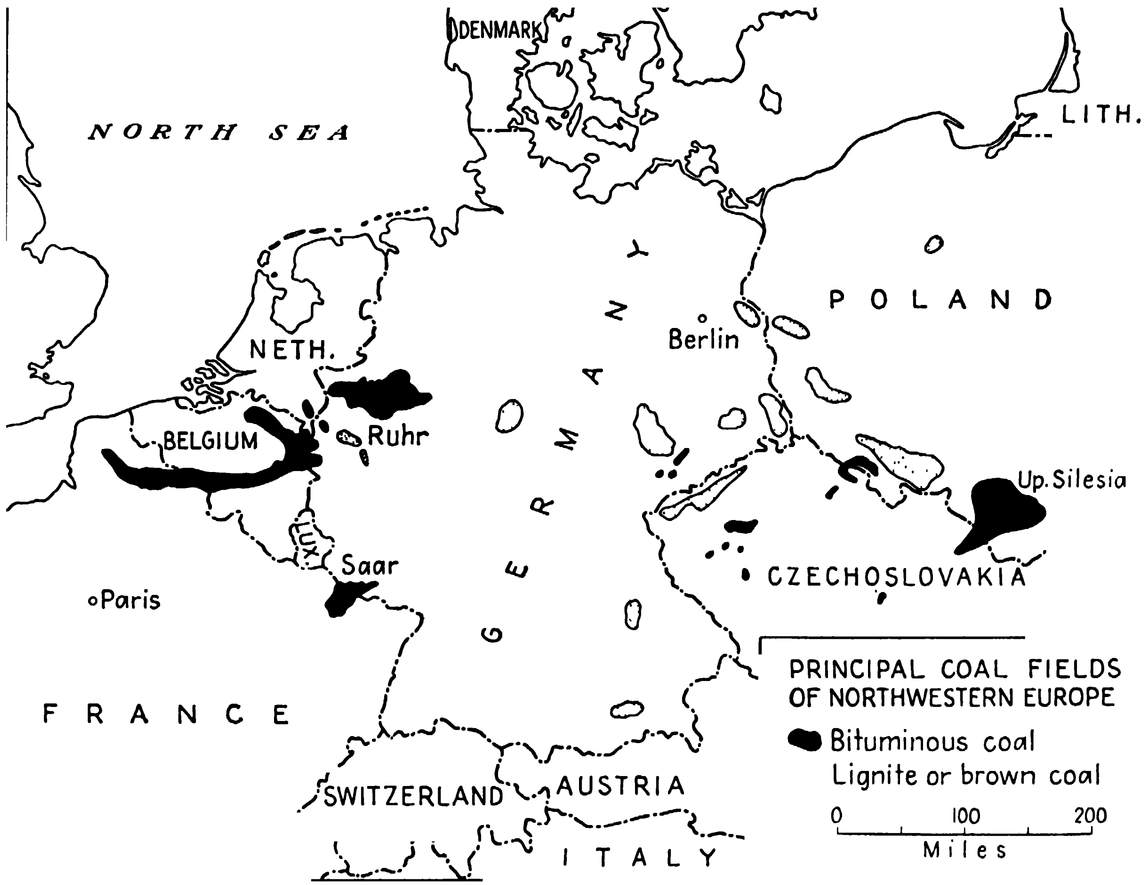


Fig. 359

industrial advancement of which may be attributed in part to these sources of fuel.

668. *British coal fields* occupy no less than six distinct regions in England, Scotland, and Wales. Mainly the coal beds are of Carboniferous age and contain coal of bituminous quality or better. So well distributed are they that only two parts of the island are more than a few miles removed from one or more of them (Fig. 358). Those two parts are the ancient crystalline rock region of the Highlands of Scotland and the plain of southeastern England, in which London is situated. It is probable that all the coal-bearing rocks of Scotland would have been removed by erosion had not a section of them been preserved in the rift, or graben, valley of the Scottish Lowlands (346). Associated with each of the major British coal fields is an important industrial district, and some of them, especially that of South Wales, are close to the sea and well situated for the export of coal.

Although the quality of British coal generally is superior, it is not always easily mined. The rocks of some of the fields have been subjected to severe deformation or are buried beneath thick sediments. In the South Wales field, where the highest grades of coal are found, rock folding brought some parts of the coal beds to the surface, where stream erosion exposed them and made mining simple. However, most of the easily accessible coal has been mined, and some of the workings now have followed the coal structures deep and far underground, greatly increasing the cost of production. The total quantity remaining in Great Britain is estimated

at an amount nearly one-half as great as that in the Appalachian field of the United States. It is sufficient for many years to come.

669. *The coal fields of western continental Europe* are numerous, but none covers so much area as the greater ones of North America. Moreover, some of them contain much thin coal or coal at great depths, and a few yield only low-grade coals. The more important fields and most of the better grades of coal lie in an east-west belt through the center of the continent. The ancient crystalline rocks of Scandinavia and Finland to the north of that belt and the much disturbed rocks of the Mediterranean Basin on the south of it contain either no coal or but small and unimportant fields.

The central coal belt of Europe extends from northern France through Belgium, Germany, and Czechoslovakia, into Poland. (Fig. 359.) Several of the fields lie wholly or in part in what, prior to 1945, was Germany, and they were fundamental to the great industrial strength and military power of that nation. The various fields include coals of many types: coking coal, bituminous, sub-bituminous, and lignite. Low grades of coal and even peat are much more used in continental Europe than in Great Britain or the United States.

670. *Important Districts.* Coal of good quality is mined at several points along a band of Carboniferous rocks in the western end of the central European belt. This important zone begins in northern France, crosses central Belgium, and enters Germany. Its most productive portion lies in the Ruhr Valley of Westfalen (Westphalia), east of the Rhine. That field is of particular importance because it has long been the center of the heavy iron and steel industries of Germany and because it contains a reserve of coking coal reputed to be larger than any other in continental Europe (Fig. 432). Nearby is the coal field of the politically famous Saar Basin. Another highly important district is that of the middle eastern region. Its richest coal deposits lie in

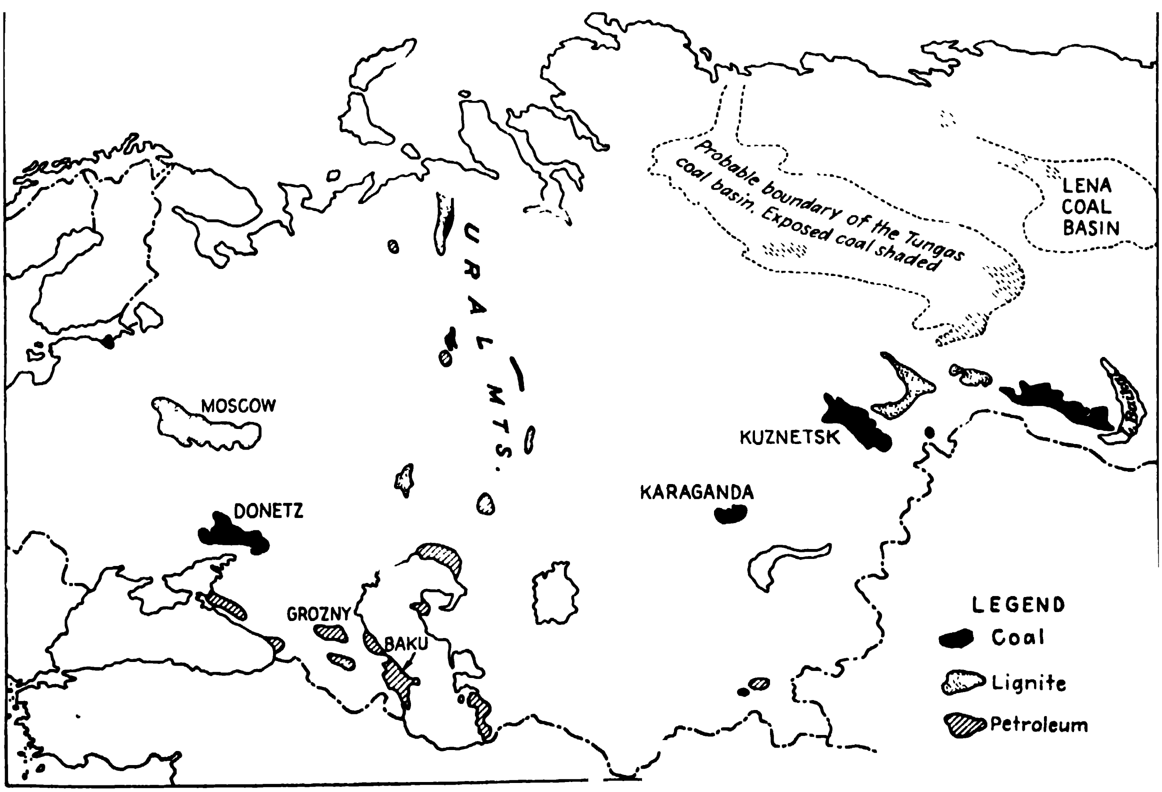


Fig. 360. The principal coal and petroleum fields of the Soviet Union.

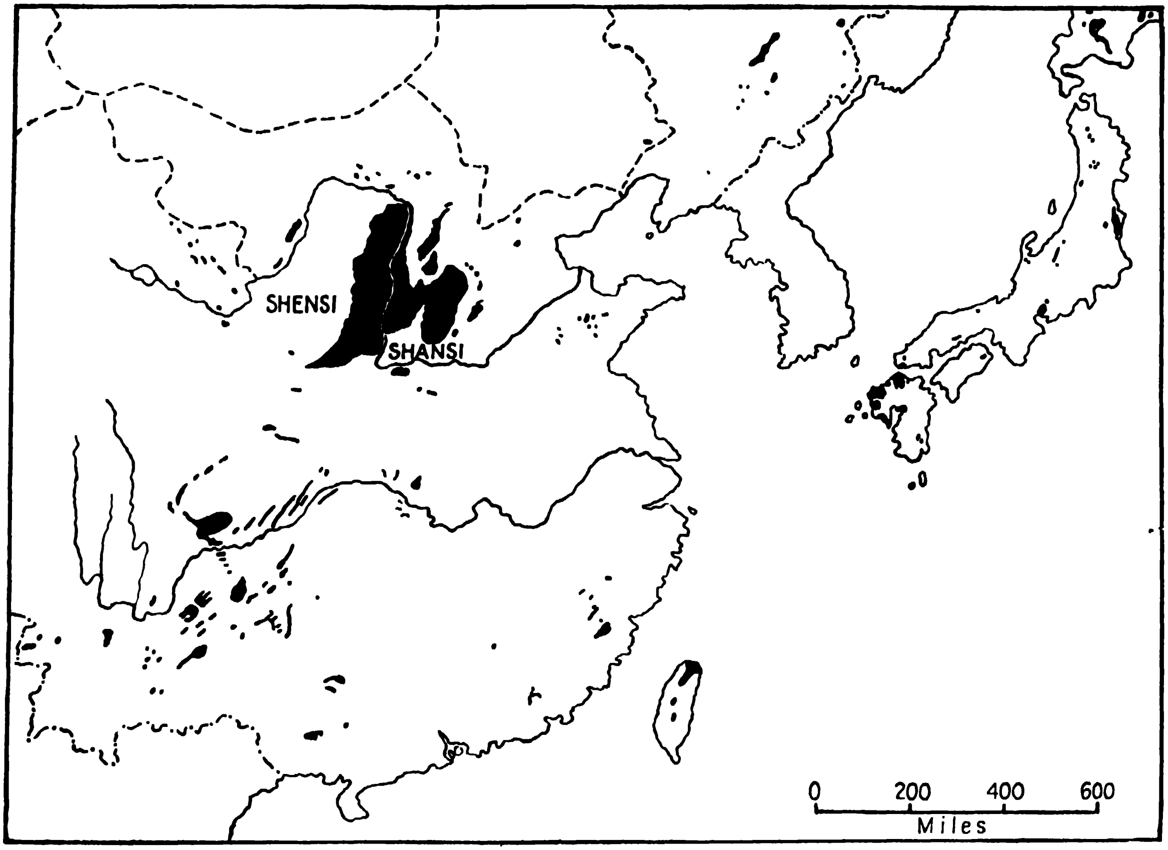


Fig. 361. The principal coal fields of China and Japan.

Poland, Upper Silesia, and adjacent portions of Czechoslovakia.

671. *The Soviet Union.* The coal fields of Soviet Russia are numerous and widely distributed, but most of the large reserve of good-grade coal is in Siberia (Fig. 360). The district of first industrial importance is the Donets Basin in southern European Russia. This greatly folded area yields some anthracite and much bituminous fuel coal, but it is valued especially for its coking coal, which is not abundant in the Soviet Lands. Donets coals supply the heavy industry of the southern region, and some is shipped to the Moscow industrial centers. Second in importance at present is the Kuznetsk Basin of southern central Siberia. It is the source of fuel for a growing industrial district, and its coking coal until recently was shipped more than 1,400 miles west to the iron and steel center of Magnitogorsk in the southern Ural Mountain region. Third in importance, and most recently developed, is the Karaganda field located midway between the Kuznetsk and Ural areas. There are smaller coal fields on the flanks of the Ural Mountains, in the region west of Lake Baikal, and in far-eastern Siberia. In the isolated forest areas of northern Siberia are extensive coal deposits whose boundaries and values are imperfectly known (Fig. 360).

The great industrial regions in and about Moscow and Leningrad do not have local supplies of good coal. There is lignite near Leningrad, and the Moscow region has a large area containing coals of sub-bituminous and lignite grades.

672. Eastern and Southern Asia. *China.* Although the full measure of the coal resources of Asia is not known, that of China is very large. The quantity of high-grade coal in that country is estimated to be greater than that of any other

country in the world, except the United States. It includes some coking coal and what probably is the largest supply of anthracite in the world. There are several coal fields in China, including those of Manchuria, but much the largest reserve lies in the northern district of Shensi-Shansi (Fig. 361), which is reputed to have 80 per cent of the total. Because of the relative inaccessibility of that field others of smaller size have been much more productive. However, the future may see a notable difference from the present, both in the relative production of the coal fields of China and in the relative importance of China as a center of manufacture.

673. *Other Asiatic countries* that have important coal reserves are Japan and India. Those of India are located in the northeastern part of the Deccan, about 150 miles inland west of Calcutta, and are now being much used in connection with the iron ores of the same region. However, they probably are not of a large order of magnitude. Unfortunately for industrial Japan the reserves of coal in that country are relatively small and scattered, and many of the beds are badly faulted. The most productive field is that of northern Kyushu, near Nagasaki.

674. Africa and Australasia. Australia, although it is a much smaller continent than Africa, has a larger coal reserve (Fig. 362). Fortunately, the principal field is located near the humid east coast of New South Wales, at or near the principal centers of population. Because of its abundance, good quality, and accessibility, Australian coal is the leading source of supply in the Southern Hemisphere, but the total reserve supply is not comparable with that of the larger fields of the Northern Hemisphere. The African coal reserve is not great, but the present production is considerable. It is obtained mainly from fields in the southeastern part of the continent, especially in the Transvaal and Natal.

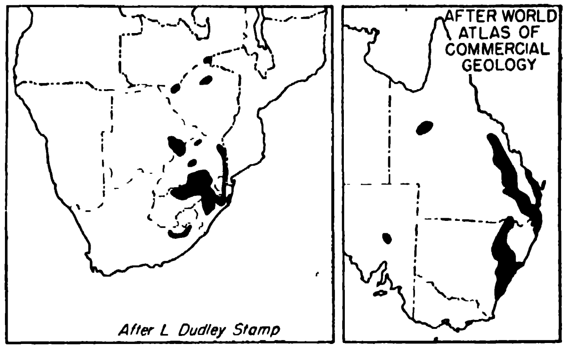


Fig. 362. The principal coal fields of South Africa and Australia.

Petroleum

675. The Structural Associations of Petroleum. Petroleum (rock oil) and its related substances natural gas and asphalt are earth materials, probably of organic origin. Whatever their origin may be, they have been so long included in the rocks that no trace of any organic antecedents is clearly discernible in them, and the very nature of the hydrocarbons of which they are composed is unlike that of the oils and other analogous compounds found in plants and animals. Because of its chemical nature, petroleum may be split up by fractional distillation into an array of products suited to many uses. Its cleanliness, compactness, and convenience as a fuel and the fact that new machines are continually being devised for using it in the production of heat and power have made it a critical item in the resource inventories of modern nations.

Petroleum and its related substances are found in quantity in sedimentary rocks only, probably because they are derived from microscopic marine organisms whose remains were originally intermingled with marine deposits. Generally they are held in permeable rocks, especially sandstones, where they exist as filling in the pore space of the rock just as it is filled elsewhere by ground water. Petroleum is found in limestones also, and some porous or slightly cavernous limestones yield it in large quantities.

Oil- and gas-bearing rocks are found in a considerable variety of physical associations and are of different geological ages. Like coal, however, they are not found among the ancient crystalline rocks of pre-Paleozoic age. Some oil sands are found at great depths, where they are buried underneath hundreds or thousands of feet of younger rocks. In some localities there are two or more oil-bearing formations, one

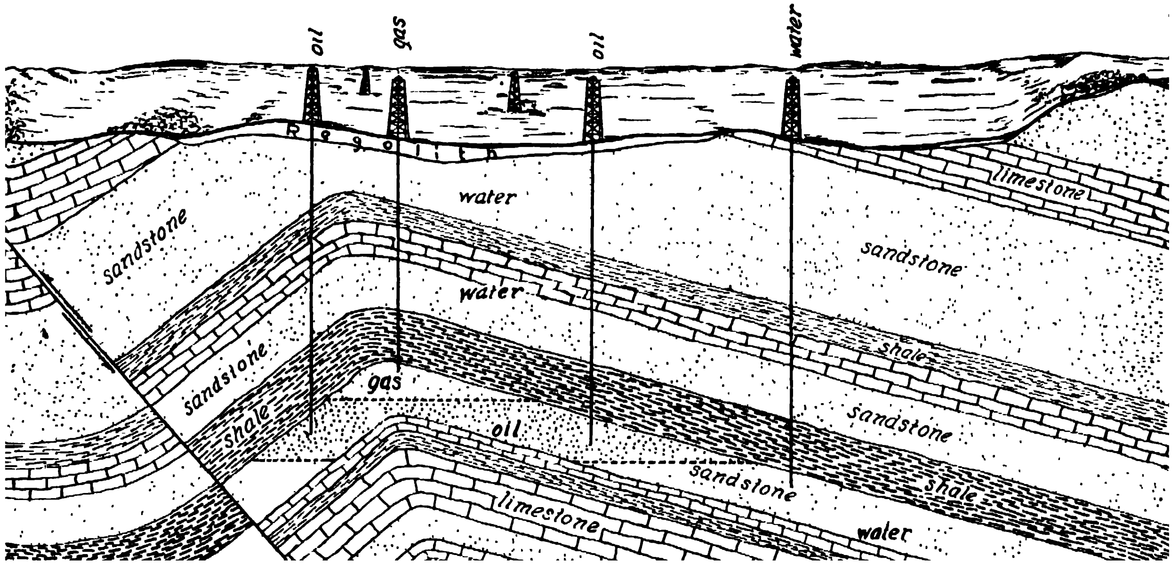


Fig. 363. A diagram to illustrate one of many types of geological structures in which petroleum is entrapped. It shows also the relation between the locations of the several wells and the nature of their products. The existence of this buried anticlinal structure is not evident from the surface relief.

above the other but separated by great thicknesses of intervening strata, and they may be of widely different geological ages. The oil and gas accumulations usually are overlain by rocks that contain abundant ground water, and many are underlain by them also. The oil and gas seldom are distributed uniformly throughout the total extent of the rock in which they occur but are gathered together in limited areas, called *pools*. The pools are accumulations of oil trapped in the porous rock of some form of structural pocket from which they cannot escape. Some of these "structures" are the tops of anticlines which are capped by shales, clays, or other impervious rocks that prevent the upward escape of the oil or gas. Other pools are found in pockets, domes, or lenses of many shapes and origins into which the oil or gas has migrated from surrounding areas and there collected. Migration into these structural traps has taken place, in the long geological past, because the oil and gas are lighter than water and tend to rise under the influence of ground water until they are caught and held beneath some impervious formation.

From such traps the oil and gas are recovered by drilling through the impervious capping rocks (Fig. 363). Through some drill holes oil is forced upward violently by the expansive force of the associated gas. Such wells are called "gushers." From others, and from most of them eventually, the oil must be brought up by pumping. Since the oil is contained in the small pore spaces in the pervious rock, not all of it can be recovered by pumping. Much of it remains as films of oil clinging to the rock particles, or its flow is impeded by the collection of tarry substances. Even with the most improved methods it is probable that half the original oil remains in the ground when pumping becomes unprofitable and the wells are abandoned. With poor methods, no more than 15 or 20 per cent of the oil may be recovered.

The manner of occurrence of oil and gas has an important geographic consequence. Because the structures suitable for petroleum collection commonly are small and deeply buried (some of them more than 2 miles below the surface), it often is impossible accurately to predict their exact location and extent or even their presence. When one structure is found in a region, it seldom is possible to predict how many others may be found nearby and still less possible to esti-

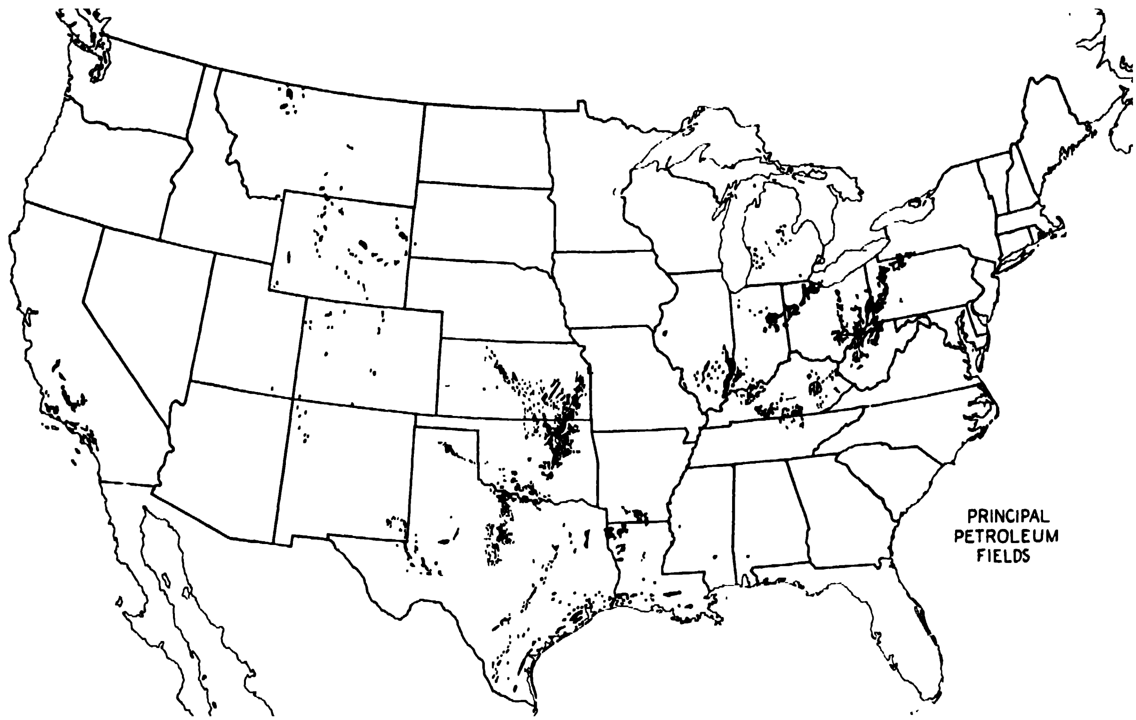


Fig. 364. Many of the pools included in the principal petroleum fields of the United States are very small. Only the larger have been included on this map, and the areas of many of them have been enlarged or combined to make them visible at this map scale.

mate the volume or value of their contents. Confident appraisal of the petroleum reserves of the nation or of the world is, therefore, not so readily made as in the case of coal resources. It must suffice, in the evaluation of the importance of petroleum and gas as elements of regional equipment, for the student to become acquainted with those fields which have either present importance or proved resources for the near future.

AMERICAN OIL AND GAS FIELDS

676. Fields in the United States. Nature has endowed the United States with several regions in which petroleum and gas are found, and the production and consumption of those fuels in the United States far exceed that of any other country. In 1947 this country produced about 62 per cent of the world's oil, but unfortunately it is credited with only one-third of the world's proven reserves. Each of the regions includes a number of subdivisions, or fields, and many localities in which are found individual oil structures the total number of which is great. In some of the structures both oil and gas are found together; some yield oil but not much gas, and others yield gas alone. In every productive field also are structures that already have yielded all that they are capable of producing economically, and they have been abandoned. There are some that have passed the maximum of production, and still others that are now at the peak of their productive lives. Doubtless there are, in most of the fields, additional pools which remain undiscovered and hold a reserve for the future. The active life of most pools is relatively short, and already some of the fields have declined in production until they are but minor factors in the national output. The question of how long the United States can maintain its present abundant petroleum production is not capable of assured answer. A feverish search goes on for new pools or for new structures at greater depths, or even for new fields in relatively unproductive

Fig. 365. A portion of the Mid-Continent Oil Field in southeastern Kansas, showing the many individual "pools" that lie within the area. (*After W. H. Emmons.*)

areas such as Alabama and Florida. In 1947 more than 33,000 new wells were drilled to an average depth of nearly 3,500 ft., and the proven reserves of the country were increased a little beyond what they had been a year preceding. The known supply was then estimated to be sufficient for about 12½ years at the prevailing rate of production. But in that same year, for the first time, United States imports of petroleum and its products exceeded exports, and the demand continues to increase rapidly. The need for conservative practices in the production and use of these essential fuels is evident.

The several principal regions of oil and gas production are indicated in Fig. 364. They are, from east to west, the Appalachian, Eastern Interior, Mid-Continent, Gulf Coast, Rocky Mountain, and California regions. The states in the Mid-Continent and Gulf Coast regions have long been the most productive and contain the greatest proven reserves. They are followed by California. Texas alone is estimated to have more than 56 per cent of the nation's total, and adjacent states have enough to increase the reserves of the Mid-Continent and Gulf Coast regions combined to nearly 70 per cent. California is credited with nearly 15 per cent of the United States reserves, and no other state except Wyoming is believed to have as much as 2 per cent.[1]

677. *The Appalachian Region.* The first oil and gas field to be developed on a modern scale was in the Allegheny region of America. That region was for many years the most productive in the world. The fuels are obtained from many fields, and pools are found in the early Paleozoic rocks (mainly sandstones) which incline gently westward from the highlands. They extend intermittently from western New York to Tennessee, and the region, as a whole, is of greater extent than the important coal field which includes younger and higher rocks that are found in the same general area. Petroleum from the Appalachian field is noted for its superior quality, which involves low sulphur content, ease of refining, and the fact that, upon distillation, it leaves a residue of paraffin rather than asphalt. Some gas is found in association with oil in most of the pools of this field, but also there are many pools of gas with which no oil is found. The most productive part of the field is its central portion, located in southwestern New York, western Pennsylvania, and northern West Virginia. Although its yields of oil still are considerable, it has passed, many years since, the peak of its productivity, and it is now credited with only about 1 per cent of the nation's reserves. Much natural gas remains, however—a resource of vital importance for household and industrial use in the region—

[1] Statistics of petroleum production and reserves quoted in this and the following paragraphs are from *Oil and Gas Journ.*, Vol. 46, No. 39 (annual number), Jan. 29, 1948.

and it is closely related to the growth of certain types of manufacture there.

678. *The Eastern Interior Region.* Fields of importance are located in Ohio, Indiana, Illinois, and Michigan. The Michigan fields are new but relatively small, while the others, formerly of great importance, have declined. The greatest of them is that which lies in southeastern Illinois and adjacent Indiana. Formerly it yielded oil of high quality and a large quantity of gas, but the latter resource has dwindled also.

679. *The Mid-Continent region* includes several widely scattered fields and hundreds of pools in Kansas, Oklahoma, central and western Texas, southeastern New Mexico, southern Arkansas, and northern Louisiana (Fig. 365). Petroleum, of both paraffin and asphaltic types, is found in abundance through a series of rocks covering a wide range of geologic time. This region has been producing for many years. Many of its pools have been exhausted, but new ones have been discovered, and the practice of deeper drilling has reached oil in older rocks at lower horizons. Gas is abundant in this region also. However, owing to small urban population and slight industrial development, there is but limited local market for gas, and much of it has been wasted. Pipe lines now carry gas from west Texas to industrial consumers far to the north and east.

680. *The Gulf Coast region* includes numerous pools found in the young rocks of coastal Louisiana and Texas, some of them in association with the coastal salt domes or mounds underlain by deposits of rock salt (719). Until lately the known reserves were confined almost entirely to the coastal margins west of the Mississippi River. Recent discoveries in Mississippi, Alabama, and Florida seem to extend the Gulf Coast fields eastward, but the presently known reserves of all three of these states combined do not exceed 3 per cent of the national total (Fig. 366).

681. *The Rocky Mountain region* is comprised of many fields distributed over a large area which is mainly in Wyoming, although it ex-

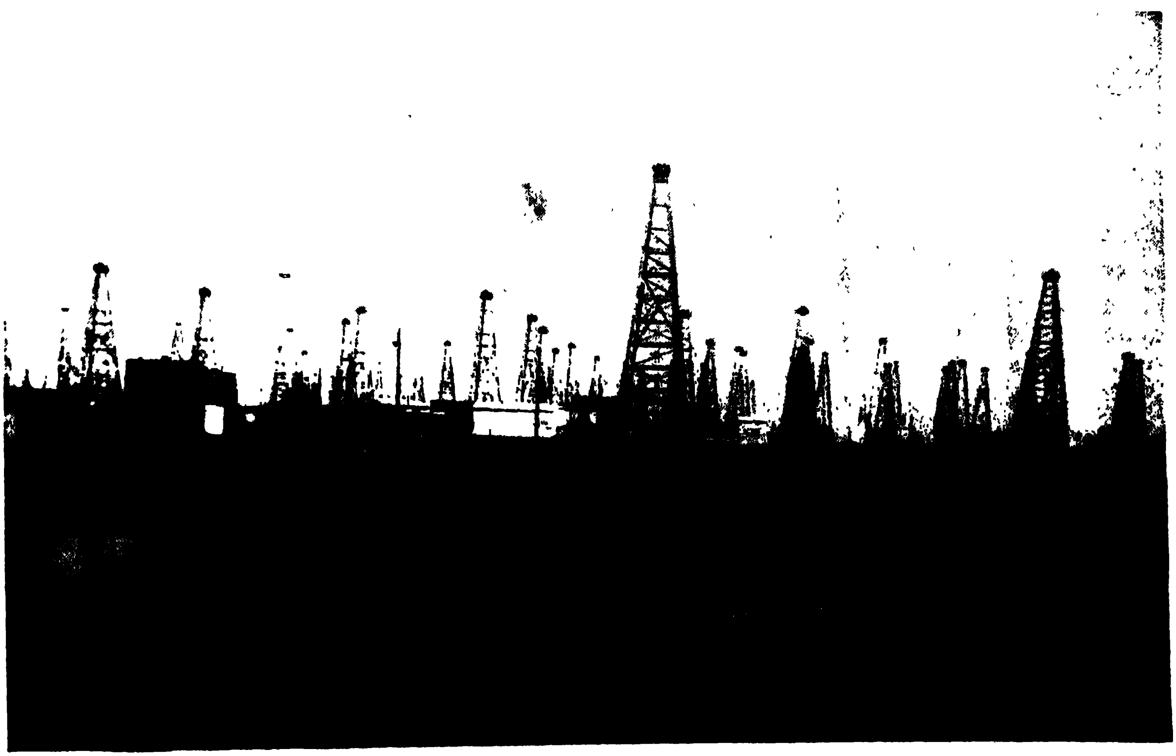


Fig. 366. One of several oil pools in the Louisiana section of the Gulf Coast Field.

Fig. 367. The principal oil fields of the Caribbean region are in Venezuela, Colombia, and eastern Mexico.

tends northward into Montana and south into Colorado. It is the least productive of the major oil regions of the United States.

On the far northern coast of Alaska there are indications of petroleum also. The United States government has created there a reservation of 35,000 square miles extent whose future production is to be held for the use of the naval forces. Some wells have been drilled, but the oil reserves of the region are unknown.

682. *The California Region.* The oil and gas fields of California are distributed over a belt that extends from the environs of Los Angeles northward toward San Francisco. Some of the fields are located in the plains and hills of the southern California piedmont district, some in the San Joaquin Valley and the Coast Ranges, and others on the very shoreline itself. As a whole, the California region is highly productive and ranks second only to the Mid-Continent in importance. Its oils mainly are heavy and of the asphaltic type.

683. *Canadian Regions.* Canada apparently is not so well endowed with petroleum and gas as it is with coal. In 1947 the output of oil in Canada, as compared with that in the United States, was in the ratio of about 1 to 275. A small amount is obtained in that section of Ontario north of Lake Erie, but the center of interest now lies in the plains of Alberta, especially the district near the city of Edmonton where promising new discoveries have been made. Farther north in Alberta seeps of bitumen are known, and still farther north in the Mackenzie River basin are the oil reserves made famous by the "Canol project" of the Second World War period. These are isolated by distance, however, and apparently they are of limited extent. The total reserves of Canada are estimated at only one-fifth of 1 per cent of the world supply. Their present importance is relatively small.

684. Caribbean Regions. Bordering the Caribbean Sea are two productive oil regions (Fig. 367). One of them, on the coast of Mexico, includes fields near Tampico and Túxpam. These began to yield abundantly early in the present century and for some years gave Mexico

second rank among the oil-producing countries of the world. They now have passed the peak of their productivity, and although the output still is considerable, Mexico has less than 2 per cent of the world's proven reserves. A second region includes several fields distributed along the northern coast of South America, mainly in the Maracaibo and Orinoco basins of Venezuela, with smaller amounts in Colombia and the island of Trinidad. Venezuela has nearly 12 per cent of the world's known reserves and ranks next after the United States among the countries of the Western Hemisphere in this respect. Seepage and evaporation of volatile constituents from an ancient pool in Trinidad gave rise to the famous asphalt lake of that island, where hardened asphalt, removed from the surface, is replaced by the slow upwelling of new supplies from beneath. The recent large yields of oil in Venezuela have enabled that country to rise to second place among the producing countries of the world.

685. South America, beyond the Caribbean borders, gives some evidence of widespread occurrence of petroleum. Of the several countries, only Argentina, Peru, and Ecuador now have important production. However, their combined output is less than that of Mexico. The total resources of all the Americas (North, Caribbean, and South) are not sufficient to give the Western Hemisphere quite half the known reserves of the world (48.7 per cent, as of 1948).

EURASIAN OIL FIELDS

686. General Distribution. The presence of oil and gas is known in many localities in Eurasia, Africa, and Australia through producing wells or natural seepages of gas, oil, or tar. However, Africa and Australia have no proven reserves of significance, and fields of large present output or such as give assurance of great future importance are confined to Europe or to Asia and its bordering islands.

It is of great significance that although the financial interests of the leading west-European countries control supplies of petroleum elsewhere, not one of those countries contains within its own borders any significant petroleum supply, and the same seems to be true of China and Japan. The largest present output and the greatest known reserves lie in three regions: (*a*) southeastern Europe, especially southern Russia; (*b*) the Persian Gulf region; and (*c*) the East Indies.

687. The Oil Fields of Southeastern Europe. Some oil has been produced for many years in Poland, but it has declined in importance. New but small production has been developed in both Austria and Hungary since 1945, and the Ploesti fields of Rumania achieved great fame during the Second World War because of the struggle for their control as a source of supply for Germany. However, the oldest, most persistent, and most productive fields in Europe are in southeastern Russia adjacent to the Caucasus Mountains and the Caspian Sea. Of several fields in this region those near Baku, on the peninsula of Apsheron, and Grozny, north of the Caucasus, are most famous (Fig. 360). Oil from those fields enabled Russia to lead the world in production until the opening of the present century. Although its output in 1947 was less than one-tenth that of the United States, Russia produces more than 75 per cent of all the oil of Europe and is the largest single oil producer among the political divisions of the Eastern Hemisphere. Its reserves are mainly in the Caucasus region and in the far-eastern island of Sakhalin, north of Japan. The proven reserves of the Soviet Union total less than 8.5 per cent of those of the world or one-fourth those of the United States. The vast expanses of western Siberia may possibly contain as yet undiscovered reserves, but in eastern Siberia the prevalence of ancient crystalline rocks does not favor such discoveries there.

688. Oil Fields of Southern Asia. The oil fields of southwestern Asia, or the "Middle East," are located mainly in Iran, Iraq, Saudi Arabia, Kuwait, and smaller political subdivisions near the Persian Gulf (Fig. 368). These areas, taken together, produced in 1947 only about one-sixth as much oil as the United States but considerably more than the Soviet Union. However, the proven reserves of the region are large, about 40 per cent of the world's known

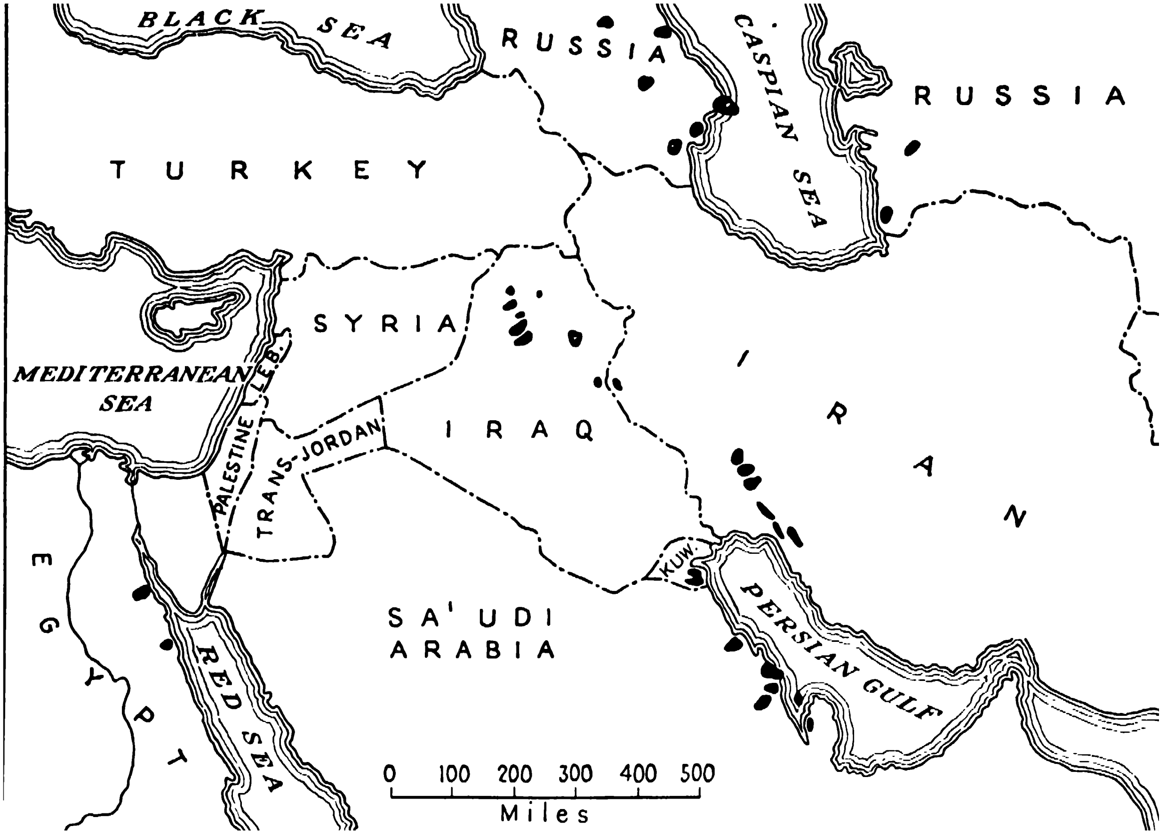


Fig. 368. The principal oil fields of the Near East and the Caucasus. The Near Eastern fields include those of Saudi Arabia, Kuwait, Iran, Iraq, and Egypt. Those in the Caspian-Caucasus region are the most productive fields in Russia (see also Fig. 360).

supply. That is nearly as much as the reserves of the United States and Soviet Russia together. One field in the small sheikdom of Kuwait is ranked as the world's largest single oil reservoir.[1] These facts help to explain why so many problems of world politics and economic strategy originate in or near this part of Asia.

The known petroleum reserves of southeastern Asia are smaller in size but by no means unimportant. They are widely scattered, the more important being in the Indonesian region, especially Sumatra, British Borneo, Burma, and New Guinea. These have total proven reserves of less than 2 per cent of the world's known supply. They suffered much from the devastation of war, and their combined output was, in 1947, only about 1 per cent of that of the United States.

[1] *Oil and Gas Journal*, Jan. 21, 1949, p. 235.

SUPPLEMENTARY OIL RESOURCES

689. Oil Shales. The recovery of petroleum from underground ceases when the flow has decreased to the point where the cost of pumping exceeds the value of the oil recovered. It has already been noted that when wells are abandoned much oil still remains underground but it cannot now be economically recovered (658). This stage has already been reached in so many pools in the United States that, although new discoveries maintain the supply at a high level, fears are expressed concerning the future. In 1948 the Secretary of the Interior proposed what seemed an enormous project for the production of synthetic petroleum substitutes at the rate of 2 million barrels per day. Yet, if that could be accomplished, the output would be less than 40 per cent of the present supply

which is obtained from wells. The sources from which synthetic oils could be obtained are two: oil shales and coal.

In the United States and elsewhere, large supplies of oil-yielding organic matter are contained in compact shales. The material does not flow and hence cannot be recovered by pumping. Petroleum has been obtained from rich oil shales of that kind in Scotland and elsewhere. However, the cost of production is high, because the rock must first be quarried or mined and then treated, before the crude oil, such as now flows from wells, can be obtained. For the future, there are large supplies of oil shale in western United States, especially in Wyoming and Colorado. Oil and gasoline substitutes can be produced also from coal by subjecting it to various chemical processes. This was done in Germany on a large scale during the Second World War, but it also is relatively costly. In any case, these sources will be expedients adopted to supplement a failing oil supply. It is likely that the student who reads this will, within his lifetime, live in a United States that no longer includes petroleum in the list of its abundant and cheap earth resources.

CHAPTER 27: *Ores and Other Economic Minerals*

690. Classes of Mineral Resources. In addition to water and the mineral fuels, the earth provides many inorganic substances for human use. In the list are the raw materials of a wide array of industries. The substances are of great diversity and include some as different from each other as the crude rocks and sand used in road construction are different from the fine metals and gems that enter into the making of an expensive watch. The mineral resources drawn upon to supply these needs may be grouped, according to the purpose for which they are produced and the manner of their treatment, into (*a*) the ores of the metallic minerals and (*b*) the solid, nonmetallic, nonfuel minerals. Those of the first group are prepared for use by treating with one of several processes of mechanical concentration or chemical reduction, and from them the metals are obtained. Those of the second group sometimes are used practically as they come from the earth. The list of the metals is a long one, but that of the nonmetals is longer. In the latter are rocks, sand and gravel, clays, lime, salines, fertilizers, abrasives, gems, and many others.

The Metallic Minerals

691. The Importance of Metalliferous Ores. Before the beginning of written history men knew the value of certain metals and sought the materials from which they might be obtained. Copper and tin were alloyed to produce bronze, which was harder than either of its components. Gold and silver also were highly prized, as they are now. Later came the use of iron and other metals such as manganese, chromium, nickel, tungsten, molybdenum, and vanadium. Some of these are used separately in the arts and specific industries, while others are combined with each other, and especially with iron, in a number of industrially important alloys. Without these alloy steels modern high-speed metal-working machines and efficient technological processes would be impossible.

Of the many metals concerned, a considerable number may be classed as precious or semi-precious. These are used in relatively small quantities. While the existence of a supply of one of them, such as gold, silver, chromium, or tungsten, is important to many industries, and economically important to the region in which it occurs, it can hardly be called a basic mineral resource. The very smallness of the volume of output of each of them and the limited quantity required, coupled with high specific value, enable these and similar metals to move freely in the channels of international trade, unless tariffs and restrictive trade regulations are imposed to prevent it. In a sense, the whole world draws upon the same sources of supply. Even a distant country enjoys almost the same advantage from such a resource, except in time of war, as does the country in which it is produced. A few metals that are used in large quantities, especially iron, may be thought of as fundamental resources. This is particularly true if they occur in close proximity to supplies of the fuel needed to smelt them. So much of iron and its ores is required, and they are of such comparatively low specific value, that they do not move in the channels of international trade with the same ease as do those of the other class. They do, indeed, move to some extent, but the possession of a domestic supply of iron ore is considered always, next to a

supply of coal or petroleum, a matter of major economic importance by the great nations.

In the world of modern industry, therefore, ores of the metals, precious and nonprecious, are elements of great significance in the complex of things that go to make up the natural equipment of regions. Because of that fact, it is necessary for the student of geography to grasp at least the fundamentals of those earth conditions upon which the presence or absence of valuable ores is likely to depend and to know the broad features of the world distribution of the most important of these substances.

692. The Common Physical Associations of Ore Deposits. An ore deposit is a concentration of a metallic mineral, or one of its chemical compounds, sufficiently rich in the metal so that it is profitable to use it. Some metals, *e.g.*, gold and copper, are found locally in the metallic, or "native," state. More commonly the metallic elements occur in chemical combination with other elements in the form of sulphides, sulphates, oxides, carbonates, and other compounds, from which they must be set free by processes of reduction called *smelting*. Usually, also, the valuable compounds are intermingled with some quantity of rock or earthy material, called *gangue*, from which they must be separated by mechanical means.

The local concentration of minerals by natural processes into ores of profitable quality is believed to have come about in several different ways, which may be touched upon here only because they have to do with the distribution of regions of mineral occurrence. Some, for example, appear to have originated at the same time as the igneous rocks in which they are found but to have separated from them while yet in the liquid molten state because they were heavier or for various other reasons. Others seem to have been thinly distributed in the original rocks and to have separated out later through some process of concentration, especially by the slow chemical work of ground water. Traces of metallic minerals are found in many rocks, both igneous and sedimentary. In liquid igneous intrusions it is possible, as has been stated (332), for molecules of like kind to come together and separate from the parent mass during the slow process of cooling. However, when valuable minerals are distributed through solid rocks, they are more likely to be concentrated by the work of solutions. This may come about as a result of several processes which, in general, do either one of two things: (*a*) Some solutions that contain molecules of valuable mineral, and perhaps others as well, bring them together and deposit them in greatly enriched zones. The deposition may take place in cavities, thus forming such features as mineral veins, or it may take place by a process of replacement, similar to that of petrification (366). (*b*) The work of solution may largely remove the rock minerals associated with those having valuable properties, leaving the latter behind in greatly concentrated or enriched form. While these processes may be accomplished by the ordinary cold waters of the ground, it is likely that the result is brought about more readily by the steam and hot waters associated with igneous intrusions. Not only is hot water more active chemically, but those waters are likely to contain gases and solutions derived from the molten mass which, themselves, may contain some of the valuable minerals or may bring about chemical changes in the rocks with which they come in contact.

It is not surprising, in view of the foregoing facts, that rich mineral ores are more often found (*a*) in regions that have at some time been affected by igneous intrusions, (*b*) in regions of crystalline rock where the processes of metamorphism have been accompanied by great pressure and the development of heat, or (*c*) in regions where both igneous activity and metamorphism have operated together. This association of conditions clearly has an important relation to the world patterns of distribution of the metallic mineral resources. Although there are some notable exceptions, it is broadly true that the great areas of undisturbed sedimentary rocks are poor in the ores of metals (see Plate IV). This is exactly the opposite of the relationship found to exist in connection with coal and petroleum. Conversely, it is true that the principal areas of ancient crystalline rocks, the bases

of old worn-down mountains, and regions of young complex mountains are likely to have localities in which mineral ores may be found. Ore deposits are more often discovered in mountain regions not merely because of the existence there of more of the conditions favorable to their formation but also because of conditions favorable to their discovery. The vigorous erosion characteristic of mountains tends to dissect the rock structures and lay open to view those associations of physical features and rock composition by which the prospector for minerals learns to recognize the existence of ores.

IRON ORES AND THEIR DISTRIBUTION

693. The Physical Associations of Iron Ores. With the exception of aluminum, iron is the most abundant of the metallic minerals in the rocks of the earth (328). Because it is so easily oxidized or rusted, it is seldom found in metallic form but in some chemical combination. The more important of these are (*a*) *hematite*, Fe_2O_3, red or gray iron oxide; (*b*) *magnetite*, Fe_3O_4, black magnetic iron oxide; (*c*) *siderite*, $FeCO_3$, iron carbonate; and (*d*) *limonite*, $2Fe_2O_3 \cdot 3H_2O$, brown hydrous iron oxide. The red and brown oxides are particularly abundant, since they are scattered widely but thinly through a large part of the regolith and give the common red, brown, or yellow colors to it. Only a little of it is required to give a strong color, and ordinary earth has not enough iron in it to make it profitable for use as an ore (621). Pure hematite and magnetite contain as much as 70 per cent of metallic iron, but large deposits of ore seldom are pure, since they contain admixtures of gangue minerals, especially silica. Some are known, however, that yield large amounts of ore containing 55 or more per cent of its weight in iron. Most of the ore used in the world must, in order to be profitable under present economic conditions, contain more than 30 or 35 per cent of iron. In the Lake Superior region of the United States and in Sweden relatively little ore is now mined that does not contain at least 50 per cent of iron. Some iron-ore deposits contain gangue minerals, such as phosphorus, which are not in large quantity but are difficult to get rid of in the smelting process. That makes the ores less valuable. A few ores, on the other hand, contain lime, which is an aid in the smelting process, and they are made more valuable thereby. The latter are known as self-fluxing ores.

It is clear, therefore, that although iron is a very abundant metal, the distribution of usable ores of iron is a matter of national concern. Those deposits of largest present value are (*a*) high in metallic iron, (*b*) low in objectionable impurities, (*c*) capable of being inexpensively mined, and (*d*) situated so that they may be transported cheaply to regions where the other necessary ingredients of iron manufacture are easily assembled near a large market for iron and steel. Few iron-ore deposits meet all those qualifications. A few, which meet enough of them, have attained international importance and should be known. Among them the outstanding deposits, measured by their present contributions to the iron industries of the world, are those of the Lake Superior region of the United States, northeastern France, Great Britain, Sweden, Soviet Russia, Germany, and Spain. Others of large potential importance require consideration also.

694. The Iron Ores of the United States. In the United States much more iron ore is mined and used than in any other country in the world. This is in part made possible by the high quality, ease of mining, and convenient location of some of the ores of the Lake Superior region. There are in that region, which includes parts of northern Minnesota, Wisconsin, and Michigan, several bodies of ore (Fig. 369). All of them, however, are found in the ancient crystalline rocks of the Laurentian Shield, which in that region extends southward from the principal area of those rocks in Canada. Furthermore, there are several other bodies of usable ore in the United States besides those of the Lake Superior district.

695. *The Lake Superior ores* are hematite of a desirable grade. Although the region contains

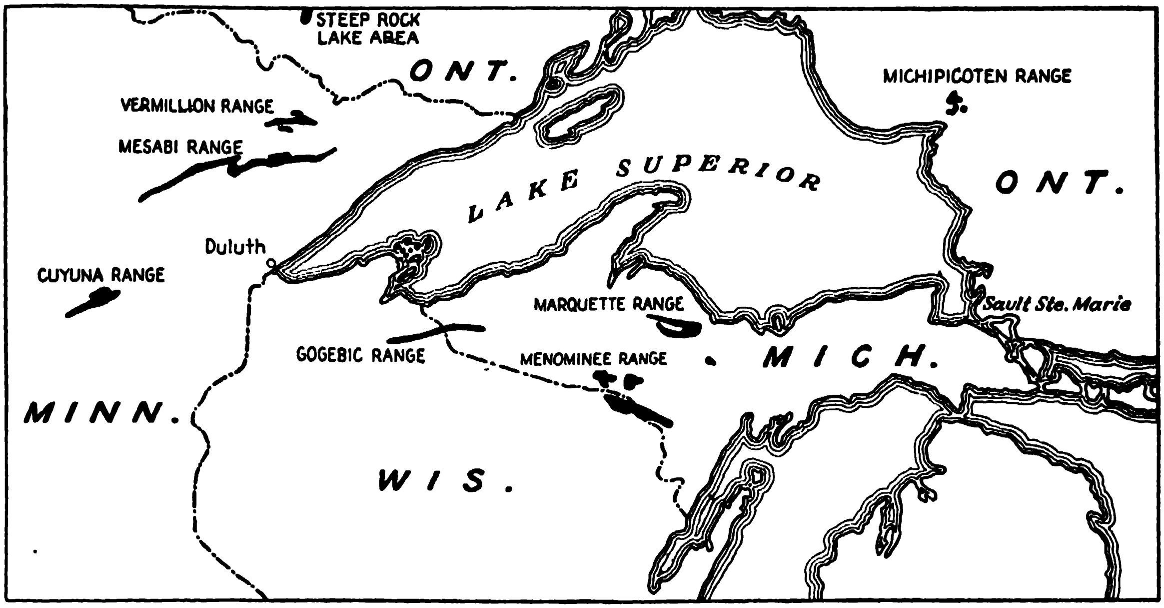


Fig. 369. The iron-ore ranges of the Lake Superior region.

large quantities of low-grade ore in which the proportions of silica and other gangue minerals are high, those mined up until recent years were very rich, the average iron content being about 55 per cent. Quite as important in the development of the American steel industry is the fact that these ores are prevailingly low in phosphorus. In many iron ores that element is as much as one-half of 1 per cent of the total. In the Lake Superior ores it generally is less than one-tenth of 1 per cent. Ores with more than that quantity of phosphorus could not be used in the manufacture of steel by the rapid and cheap Bessemer process, which played an important part in the history of the American industry, although it has largely been supplanted now by other processes which are able to deal with ores of higher phosphorus content.

The physical situation of the Lake Superior ores is of as great advantage as their chemical composition. They have been concentrated in the ancient rocks by the work of ground waters and lie in pockets which, in general, are near the surface. Particularly in that district of northern Minnesota called the Mesabi Range, the most accessible and highest grade ores were included in a broad and shallow structural trough covered only by an overburden of glacial drift. When the overburden was stripped away, the ore could be removed from open pits by power shovels loading directly into railway cars (Fig. 370). This has been the most productive iron-ore body in the world. Open-pit mining has been possible in limited parts of some of the other Lake Superior ranges also. However, rapidly increasing peacetime requirements and the hurried demands of two world wars have drawn so heavily upon these sources that the reserves of rich open-pit ores are approaching exhaustion. In the other Lake Superior ranges considerable good ore is mined underground from deposits broken and displaced by faults, but underground mining is a much slower and more difficult process. For the near future new sources of ore must be found, and the maintenance of the present organization and distribution of the American iron and steel industry seems to require that the ore come from the Lake Superior region. It is not considered safe, for both economic and military reasons, to depend on imported ores, especially those drawn from far-distant sources. To supply this future demand there are in the Mesabi Range enormous tonnages of an iron-bearing rock called taconite. This is the parent

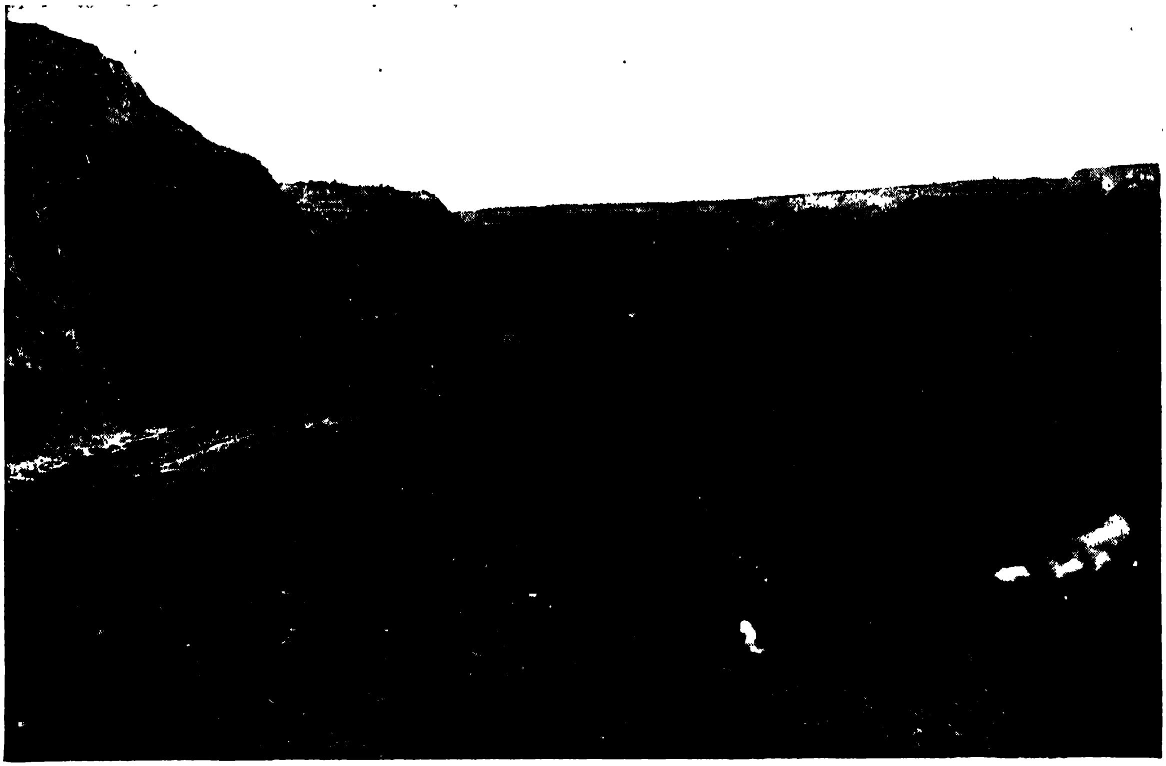


Fig. 370. Mining iron ore in an open pit in northern Minnesota. Open-pit ore of high quality is no longer abundant in the Lake Superior region. (*Courtesy of the Oliver Iron Mining Company.*)

rock from which the rich ores were derived by natural processes of enrichment through the removal of silica by the solvent action of underground waters. Taconite yields both hematite and magnetite, but its iron content is only about 25 to 35 per cent as compared with the 50 to 60 per cent found in the rich ores now nearing exhaustion. These low-grade ores are not suitable for direct shipment. The rock must first be quarried and crushed and then put through processes of concentration to separate the iron-bearing material from the silica before it can be transported economically. These processes have not yet been fully worked out for large-scale operation, but however done they will add greatly to the ultimate cost of the ore and of its iron and steel products.

The relation of the Lake Superior ores to regions of manufacture and market is fortunate. The construction of a ship canal through the rapids of St. Marys River, connecting Lakes Superior and Huron, provided a deep waterway for the transportation of ore almost from the mine to the very margin of the Appalachian coal field and the heart of the American industrial region. The provision of special devices and carriers for handling the ore has reduced the cost of transportation to a very low figure. For many years more than three-fourths of the iron ores mined in the United States have come from the several districts of the Lake Superior region.

696. *Other United States ores* are available in many localities, but mainly the deposits contain only limited reserves. Those now most in use are located in Alabama and New York. Among the sedimentary rocks of the Folded Appalachians are discontinuous beds of hematite which are found in localities from New York to central Alabama. These ores are most used in Alabama, where they are mined in the same district with the coal and limestone required in smelting them (Fig. 371). They are of relatively low grade, since they yield only

about 35 per cent iron, but they have the advantage of containing sufficient lime so that they are almost self-fluxing. Other considerable deposits of ore, hematite and magnetite, are known in the Adirondack Mountains of New York and at various places in the interior states, the Rocky Mountain region, and other western localities. What the relative importance of these several reserves may prove to be when the Lake Superior ores no longer dominate American production is not known.

697. Other Western Hemisphere Reserves of Iron Ore. Iron ore moves so cheaply by water that even the ample United States supply has not prevented some foreign ores from moving to meet abundant coal upon the eastern seaboard for smelting there. Most of these limited imports come from other North or South American sources, chiefly from Chile, Cuba, and Newfoundland. The two last named have large reserves of medium-grade ore available for export.

698. *Canada and Newfoundland.* Canada has the larger part of the ice-scoured rocks of the Laurentian Shield, but until recently it was not known to contain such large and easily mined ore deposits as those in Minnesota. Some of considerable value have been mined in districts both west and east of Lake Superior, but the most productive deposit is that mined underground on a small island near St. John's, Newfoundland. The reserve in this deposit is hematite and is large, and the ore yields over 50 per cent iron, but it is high in phosphorus. However, it has easy access to water transportation, has been used in smelteries near the coal deposits at Sydney, Nova Scotia, and some has been shipped to British and European markets.

A most important ore deposit, recently discovered, lies in the almost uninhabited region on the boundary between eastern Quebec and Labrador. This, while as yet only partly explored, seems to be one of the world's great reserves. Some of it is known to be hematite with an iron content exceeding 60 per cent and so situated that open-pit mining may be practiced. However, the region is far inland,

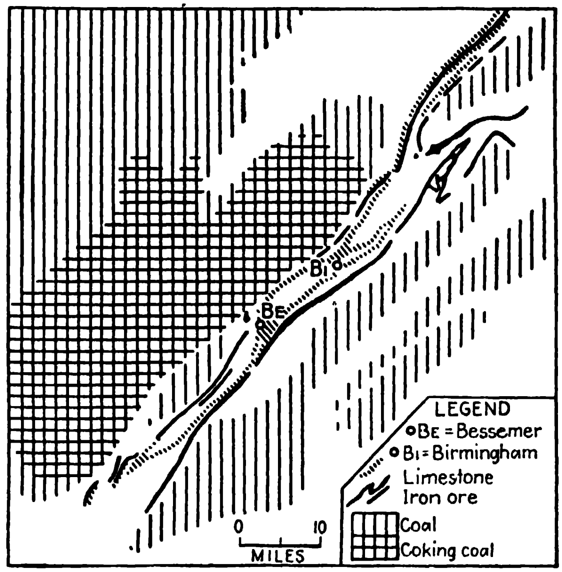


Fig. 371. Distribution of essential minerals in the Birmingham, Alabama, industrial region.

and to get ore from it to the United States coal and established smelting centers will require the construction of 350 miles of railroad to the north shore of the Gulf of St. Lawrence and then improved means of water and rail transport inland. It can hardly be expected that this region will make any large contribution to the huge requirements of the North American iron and steel industries for many years to come.

699. *Brazilian Ore Reserves.* Although Brazil does not now compete with Cuba and Chile in the export of ore, it has a remarkable supply which, for several physical and economic reasons, is not now producing much commercially. The ore fields lie more than 200 miles north of Rio de Janeiro in the ancient crystalline rocks of the Brazilian plateau. They include a number of localities which contain ore bodies of the highest quality, some hematite, some magnetite, and they comprise one of the great and rich reserves of iron ore in the world.

700. Western European Iron-ore Deposits. The iron industries of western Europe depend mainly upon European sources of ore. Like those of North America, the greatest centers of iron manufacture are located in, or close to, the principal coal fields. In only a few places are the ore and coal found together; hence, one or

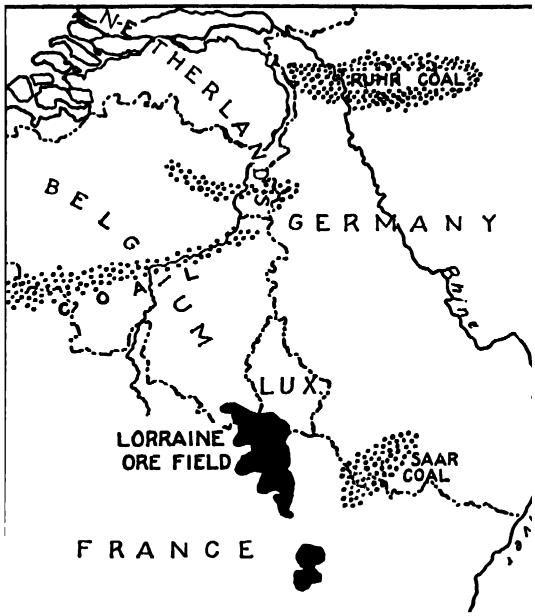


Fig. 372. Location of the great Lorraine iron-ore field of France with respect to coal fields.

the other must usually be transported. In the United States they move freely by water over the Great Lakes, and more largely the ore moves to, or toward, the coal. In one particular respect the European situation is different. Although some of the countries contain both, the numerous political boundaries of western Europe have separated several of the more important deposits of iron from those of coal, and much of the ore, especially the high-grade ore, has had to move in international trade to reach the principal smelting centers. The large iron resources are in France, Great Britain, and Sweden. That of Sweden is less in quantity than those of the other two but superior in quality. Other important sources of ore are found in Germany and Spain. Those of Germany are not adequate to the large needs of the country, but those of northern Spain, a country of little coal, have provided ore for export to England and other countries until some of the deposits are nearly exhausted.

701. *The iron ores of France* include the largest single iron reserve in Europe and one of the large ones of the world. They are found in the north-eastern part of the country in the province of Lorraine and extend across the boundary into Luxemburg and slightly into Belgium (Fig. 372). At various times part of this area has been under German political control. But whether under French or German control, these ores have contributed in some degree to the development of the German iron and steel industry. The Lorraine ores are mainly limonite and of relatively low grade, since they average only about 30 to 40 per cent of iron. However, they are sedimentary in origin and contain enough lime to make them self-fluxing, and they lie near the German, Belgian, and French coal fields and the great industrial market of Europe. They are high in phosphorus, but a special process of steel manufacture extracts that undesirable element and makes from it a valuable by-product fertilizer.

702. *The iron ores of Great Britain* are fairly abundant but are scattered, of different kinds, and mainly of low grade. It has long been the practice of British smelters to supplement the domestic supply with other ores, especially the better grades imported from Sweden, Spain, North Africa, Newfoundland, and elsewhere. However, of domestic low-grade ores Britain has a supply sufficient for many years, and economy is enforcing a greater dependence upon them. They are distributed in several localities, the larger reserves being in eastern England, especially the Cleveland district in Yorkshire (Fig. 358). They are closely associated with supplies of coal and limestone.

The iron ores of Sweden are only moderately abundant, but the principal deposits are noted for their high quality. They are mainly magnetite and average 55 to 65 per cent iron. The largest and best deposits are situated in the crystalline rocks of the far-northern part of the country. Since there is almost no coal and but little iron manufacture in Sweden, the ores are exported, in normal times, to Germany, Britain, and other European countries.

703. *Iron-ore Deposits in the Soviet Union.* The Soviet Union has large reserves of good iron ore, the more important of which are found in two localities. These are Krivoi Rog, in the southern Ukraine, and Magnitogorsk, at the

southern end of the Ural Mountains. The former is the larger and normally the more productive. It is located about 300 miles west of the Donets coal basin, with which it is associated in the development of the Ukrainian region of heavy industry. The ores at Magnitogorsk are not well associated with local coal, but a great expansion of industry there was enforced during the Second World War, coal being supplied from the several small deposits farther north in the Ural region and from the distant Kuznetsk and Karaganda fields in Siberia (671). Smaller iron-ore deposits in eastern Asiatic Russia are used locally in the development of an independent industrial economy there.

704. Other Significant Iron-ore Deposits. Through the vast expanses of Africa, Asia, and Australasia iron-ore deposits are known to exist in many places. Some of them now produce in sufficient quantity to provide abundantly for local industry, as do those of southern Australia, for example. It is probable that in localities as yet imperfectly explored other, and perhaps significant, resources may be found. However, of all the many iron-ore deposits known, only one appears so great as to rank among the major sources of iron in the world. That one is in India. It lies adjacent to the principal, but not highly productive, coal field of the country in a district about 150 miles west of Calcutta. The ores are hematite of high iron content; they are of great extent and are so near the surface that some at least are capable of being mined in open pits.

705. Significant Facts about the Iron Resource. Iron is the most important metal in the present-day world, and it is the second most abundant. Moreover, scattered over the earth are many places where there are ores of some present or future significance as sources of the metal. Of these many deposits only a few have now any great importance. Much the larger number have little present value because they are (*a*) small, (*b*) remote, (*c*) low in iron content, or (*d*) combined with substances that increase the difficulty and cost of smelting them. Which of the deposits of present less importance may achieve future prominence cannot be predicted, because of the possibility that new methods of manufacture of iron may, in the future, make it feasible to use as ores substances much below the present standards of good quality.

However, since iron usually is reduced from the ore by the use of certain grades of coal in the form of coke, it is important to consider in what parts of the world these two ingredients are found close together. It was stated previously that the distribution of the world's plains was such that they contribute to the commercial supremacy of the Atlantic Ocean (390). Another reason for that supremacy may be noted here. The world regions in which abundant deposits of iron ore and of coking coal are closely associated lie on the borders of the North Atlantic Basin. These include eastern United States, the countries of northwestern Europe, and Russia. In them are the present world centers of heavy iron and steel manufacture and of many other industries that depend on cheap iron and steel. There seems good geographic basis for believing that those centers will long continue, because no others appear to have better natural endowment or more advantageous situation. Some of the world's greatest reserves of ore are in Brazil and India, but the former has little, and the latter has only a limited supply of, coking coal. China has large reserves of excellent coal but no known supply of ore of comparable importance. Also, it may be noted, Japan, which strove to be a progressive industrial nation and a first-class military power, has but limited domestic supplies of coal and even less iron ore of usable grade. With respect to the basic raw materials for iron and steel manufacture the situation of the United States has been fortunate. Domestic coal and iron ore have been abundant, of high quality, and so located as to be cheaply assembled. Now that the richest and most accessible ores are approaching exhaustion, the iron and steel industry faces critical problems. Many of these have been foreseen, and tentative solutions have been proposed, all of them relatively costly. It remains to be seen whether readjustments can be made which are capable of

operation on a sufficiently large scale and quickly enough to prevent a critical shortage.

OTHER METALLIC MINERALS

706. Important Precious and Semiprecious Metals. The list of metals that have importance in modern arts and industries is so long that adequate descriptions of their several regions of occurrence would require more space than is available here. In any case, a brief account of each of so many kinds of regions might well produce more confusion than enlightenment. For that reason, comment will be restricted to the locations of the major world regions that are noted for their important productions and possible reserves of the precious and semiprecious metals as a group.

707. Productive and Potential Mineral Regions. The earth conditions favorable to the occurrence and discovery of the ores of the several metals here included must be of great variety. The generally favorable conditions have been discussed (692), and it needs only to be stated here that the principal world regions of mineralization are those of ancient crystalline rocks, or of more recent crustal disturbances, or of igneous activity. Although this is true in a general way, it is a rule that has notable exceptions. One type of exception is found in the deposits of lead and zinc ores associated with sedimentary rocks. Examples of these are the lead and zinc deposits of southwestern Missouri, southwestern Wisconsin, and adjacent Illinois, or those of Belgium or of Poland.

708. *Ores of Aluminum and Magnesium.* Other exceptions of great importance are the ores of aluminum and magnesium. Aluminum, even more abundant than iron, is like iron in that it is a constituent of earthy minerals which are widely distributed in the regolith. It is a component of common clay and other substances most of which are too low in grade to be utilized profitably. Only in a few places are there rich deposits of the earthy ore of aluminum called *bauxite*. Varieties of this substance are of different origins, but it seems clear that some are derived from sedimentary clays that have been changed through long-continued leaching by ground water, whereas others are known to have been derived by the complete weathering or laterization of igneous rocks of types that were low in iron and silica (635). The notable deposits of the Ouachita Mountain region of Arkansas are of the latter type, whereas those of France are of sedimentary origin. Large reserves of bauxite available in France, Hungary, and Yugoslavia provide abundantly for European consumption, but the domestic reserves of the United States are not great, and much of the ore now consumed is imported from British Guiana. Other deposits of bauxite are known in many parts of the world: the West Indies, Brazil, equatorial Africa, the East Indian region, and the Soviet Union. It is significant that so little high-grade aluminum ore is known to exist in either the United States or Canada.

Magnesium, another of the light metals, and its alloys have been produced in quantity only in recent years. Fortunately its sources are many. They include magnesium-bearing rocks such as dolomite, brines obtained from vast underground salt beds, and even sea water. These sources are widely distributed over the earth, and the problems which concern magnesium production are mainly those of large-scale industrial organization rather than of possession of raw materials.

709. *Sources of Atomic Energy.* The opening of the age of atomic energy, in 1945, directed public attention toward the world distribution of uranium and thorium, the principal minerals from which the fissionable materials are obtained. This is clearly a matter of the greatest concern, one which is on a plane quite different from that concerning nickel or copper or perhaps even iron ore or coal. Both these minerals are known to have fairly wide distribution in nature, but the rich deposits at present known are restricted in area. The critical deposits of uranium are located in the Belgian Congo, the region near Great Bear Lake in northern Canada, Czechoslovakia, and several localities in southwestern United States. Numerous other deposits, now believed secondary, may prove to be of major order. Thorium is derived from certain sands, the best of which

metals are found in regions of ancient rocks or of mountain structures, it may not be safely concluded that all such regions are so endowed. It is probable that lack of detailed exploration in certain of those regions may explain their present lack of known ore deposits, but that is not true of all. For example, the crystalline Highlands of Scotland and the large areas of similar rocks in Scandinavia and Finland are known by geologists in much greater detail than are those of Canada or Africa. Similarly, the geology of the Alps is known in more minute detail than that of any other mountains of the world. Yet in neither of these regions are there many outstanding deposits of the precious and semiprecious metals.

The Nonmetallic, Nonfuel Minerals

716. Minerals for Many Uses. In addition to the mineral fuels there are produced from the earth more than 50 other nonmetallic minerals. Some of them are used in their natural states, while others pass through processes of industrial manufacture and appear as components in goods having hundreds of essential uses. Rocks, sands, clays, salts, abrasives, fertilizers, gems, and many others make up the list. Most of them are found in a variety of grades or qualities which have equally varied uses. They are essential parts of the natural equipment of regions, but no limited portion of the earth contains all of them. Indeed, there are few regions, if any, that contain all of even the most essential.

Because of the great number of these substances, many must be omitted from this brief treatment. Others, the more essential or those required in greater quantity, may be grouped for consideration under two major headings: (*a*) minerals used in making utensils or in construction and (*b*) those used as raw materials in the chemical industries. A few minerals, such as lime, belong in both classes.

CRUDE MINERALS FOR CONSTRUCTION AND UTENSILS

717. Rock for Construction. Many kinds of rock and large quantities of it are used in architectural and engineering structures. In the form of cut stone, crushed rock, or gravels of stream or glacial origin, some material that will serve these purposes is found in most parts of the earth. It may seem that rock, in this broad sense, is one of the universal items of regional equipment, like the air. That, however, is not true. Some regions are endowed with rocks having unusual qualities of structure, strength, beauty of color, or ease of working. Others have none at all.

Because crude rock is heavy and of low value, it seldom moves far from its place of origin unless it has some particular quality to recommend it to a wider market. Regions in which rocks of special quality abound have, therefore, a valuable resource, especially if they also are near a large market for stone. Such a region is New England. There a vast quantity of crude rock, glacial boulders, and gravel is supplemented by special rocks in a region of igneous intrusion and metamorphosed sediments. Beautiful and massive granites, slates of parallel cleavage, and excellent marbles all are produced. The even-textured and easily worked gray limestones of southern Indiana have a national market, and some other stones of unique quality have practically world markets. Such are the lithographic limestones of Bavaria and the statuary marble of Italy.

A few regions of considerable size are practically devoid of rock. Among these are the great deltas of the world, where silt covers hundreds of square miles and rock is buried to great depths. Much larger are certain of the plains of older alluvium or the regions of deep loess accumulation. Among these is the loess- and alluvium-covered Pampa of Argentina and similar areas in the American Corn Belt, where older glacial drift and loess cover the rock strata deeply. In these regions are localities that have not even any crude rock or gravel with which to surface roads.

718. Sands, Limes, and Clays for Industry. Sand, in crude form, enters largely into construction as an ingredient of concrete, mortar, and plaster. Also it shares with lime and clay a place of importance as a raw material of

industry. Lime and clay are required in the manufacture of cement; clay is basic to the brick, tile, and pottery industries; and sand is the chief raw material in the manufacture of glass. These three substances are of common occurrence. There are, for example, river sands, beach sands, wind-blown sands, glaciofluvial sands, and pure sandstones. There are unconsolidated marls, soft chalks, and hard limestones. There are river clays, lacustrine clays, marine clays, residual clays, and shale rocks. Not many regions are without one or more of these minerals. However, qualities differ. Glacial lake clays may be good enough for the manufacture of ordinary brick and tile, but other uses have more particular requirements. Pottery clay, especially, must be pure and burn white. It usually is found in residual deposits where it has weathered from coarsely crystalline feldspars (329). Good grades of glass sand, free from iron or clay, may be sought hundreds of miles from the centers of glass manufacture. Therefore, some regions gain advantage from natural endowments of sands, limes, or clays suited to particular requirements. Some, indeed, have achieved international fame through their products, such as that which attaches to the regions of pottery clays in southern England, northern France, or Bavaria.

MINERAL RAW MATERIALS FOR THE CHEMICAL INDUSTRIES

719. Salt is one of the common rock minerals of the earth. Owing to its solubility in water, it is not abundant in the zone of free ground-water circulation. Inexhaustible supplies are available for human use, however, from the following sources: (*a*) the sea, which contains $2\frac{3}{8}$ lb. of salt for every 100 lb. of water; (*b*) natural brines, which are the waters of ancient seas trapped in sediments, now deep underground, and cut off from ground-water circulation; (*c*) deposits of rock salt, which probably are precipitates from the evaporation of water in the arms of ancient seas or in former arid interior drainage basins. Those deposits now are sedimentary rocks deep underground, where they are protected by the other sediments from the solvent action of ground water. (*d*) Another limited source of supply is found in the surface encrustations of salt in the playa and similar deposits of the interior drainage basins of deserts.

Salt is used not only as a food and a preservative of food but also in large quantities in chemical industries. It is the basic raw material from which a number of the compounds of sodium are made. For industrial uses it is obtained largely by mining rock salt or by the pumping of brines, either natural brines or those produced by pumping water down to bodies of rock salt.

Primitive peoples in many regions have found it difficult to procure sufficient salt, even for their limited requirements. Yet salt is now so readily obtained and is found in so many places that few parts of the world are without some local supply. Industrial salt, however, comes mainly from a few sources.

720. *Salt-producing Regions.* The industrial regions of North America are supplied with salt, both rock salt and brine, from abundant reserves. Thick beds of rock salt underlie large areas in central and western New York, northeastern Ohio, southeastern Michigan, and peninsular Ontario. Other large reserves are found in the buried "salt domes" of the Louisiana-Texas Gulf Coast, in deposits in central Kansas, and at various places in the southwestern states.

The industrial centers of Europe likewise are well provided with salt. There are large deposits in western England, central Germany, Austria, and southern Soviet Russia. Other populous countries, especially China and India, also are large producers of salt.

721. Sulphur has many uses in modern industry, especially in the form of sulphuric acid and for various uses in connection with the manufacture of steel, oil, paper, rayon, rubber, explosives, and in other chemical industries. It has long been obtained from deposits associated with recent volcanic activity. Some still is mined from these sources in Italy, Spain, Japan, and Chile. In the United States, which

tank farms store millions of barrels of oil awaiting shipment, and the dull red of ore piles marks the sites of some of the underground iron mines of northern Michigan. In general, however, mineral production must be visualized in terms of the number of tons of ore or coal, or barrels of oil moving out by rail, truck, boat, or pipe line along various routes from the producing area.

In many mining regions the most conspicuous features of mineral production are the top works of mines with their derricks, hoisting machinery, mills, powerhouses, loading sheds, and waste dumps (Figs. 355 and 351). Quarries and open-pit mines likewise leave conspicuous scars upon the surface. Various of these in association represent the typical mining landscape. But, since most mining is done by underground shafts and tunnels, the excavation features are not so readily observable. They are nevertheless, even when underground, important cultural features. Their nature and extent often are a direct reflection of the history of local mining and of the problems and prosperity of the industry there.

727. Mining Population and Settlements. The significance of mining in a region is reflected in various ways, especially by the percentage of the total working population that is employed in mining and similar industries, such as petroleum production. In the United States there are very few spots where that ratio exceeds 50 per cent. However, a map showing the distribution of mining centers by this means suggests some interesting facts (Fig. 376). For example, in western Pennsylvania, where miners are particularly numerous, there are so many other people employed in various industries that the percentage of miners to other workers does not generally exceed 20, and in only limited districts does it exceed 30 per cent. In Nevada, on the other hand, mining is shown to be an industry of the greatest local importance by the fact that in nearly half the state the proportion of miners to other workers ex-

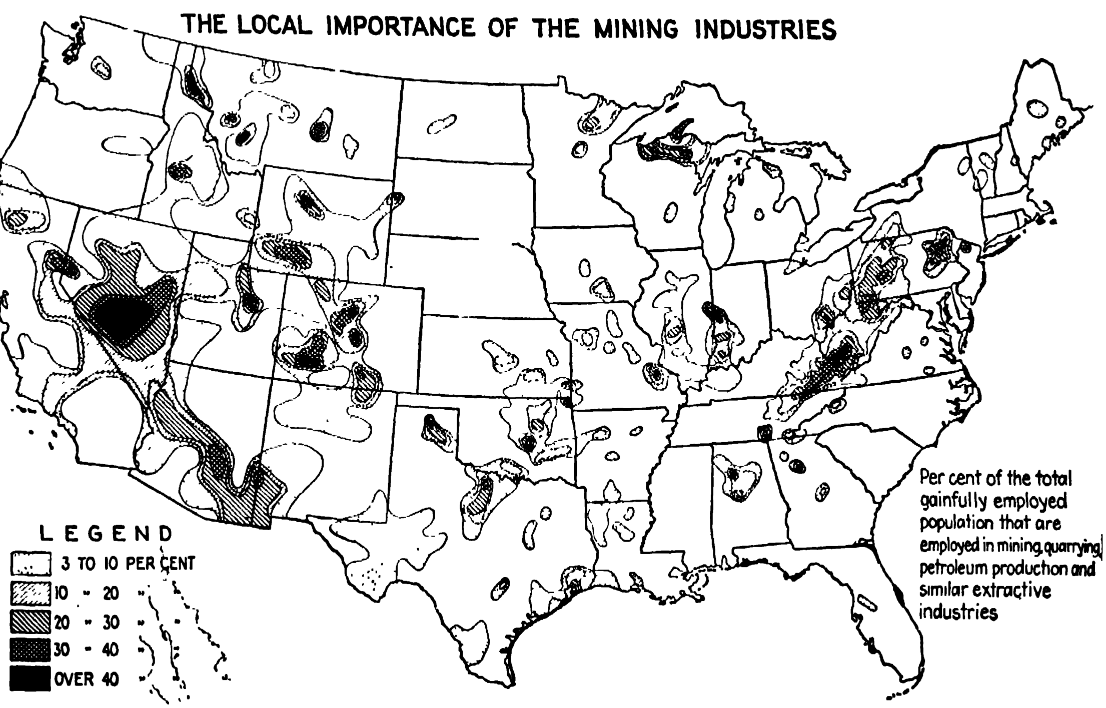


Fig. 376. This map shows the importance of mining to the people of several eastern and central coal, oil, and iron-ore regions, the positions and shapes of which may be recognized. It shows also that in arid Nevada the proportion of the total wage-earning population that lives by mining is higher than in any other state.

ceeds 20, and in one large district it exceeds 40 per cent. This is clearly due to the fact that, although miners are obviously less numerous in sparsely populated Nevada than in densely peopled western Pennsylvania, the number of those employed in manufacture is still smaller by comparison.

In mining settlements the miners' houses and their arrangement in street patterns are conspicuous elements of regional character. In general they are not noted for the beauty of their appearance or the spaciousness or sanitation of their surroundings. It has been noted previously that a large part of the world's mining industries are conducted in regions of restricted physical environment. It is perhaps unavoidable therefore that mining settlements should fail to compare favorably with agricultural or commercial settlements in the same part of the world (Fig. 356 and 373).

PART TWO

The Cultural Elements of Geography: Features Resulting from Man's Use of the Land

Introduction

728. Natural and Cultural Elements. The geographic character of most earth regions is determined by *two* sets of features: (*a*) those which are a part of the original natural or physical earth and (*b*) those which have been superimposed on the original physical area by man as a result of his living in a region and utilizing its resources. These two great groups of surface features, their forms, patterns of distribution, and characteristic associations, are the *elements* or *fundamentals* of geography. Those elements of the areal scene provided by nature, some inorganic and others organic (*physical geography*), have already been analyzed, classified, and described in Part One of this book. In the present division, Part Two, those other elements, people, and the features of material culture resulting from their occupying a region and developing its resources, are analyzed and classified. This is *cultural geography*. Nowhere does man exist upon the earth without doing something to its surface; marks of his utilization are always conspicuous within inhabited areas. This human imprint, these features of *material* culture associated with agriculture, manufacturing, trade, mining, and the other economies—houses, fields, roads, factories, domesticated animals, etc.—become, then, the immediate interest and object of study in Part Two of this book.

Some geographers would include among the elements of human geography, in addition to the material culture of a region, other less tangible aspects of its human development, such as the physical well-being of its people, their education, art, government, morals, and religious life. They argue that geography cannot be defined strictly in terms of content. Theoretically its elements are limitless. They contend that geographic quality is to be found in the *method* of treatment of earth facts, *i.e.*, in their regional associations, rather than in the *kinds* of facts. But whether the nonmaterial elements be included or not, most geographers would agree that, for the earth as a whole and for the majority of its regions, the most important elements of human geography are those associated with the efforts of human beings to make a living, *viz.*, the facts of land utilization, including agriculture, manufacturing, trade, and mining.

729. Lack of a Ready-made Classification of Culture Features. Unfortunately there does not exist any such careful and systematic ordering and classification of the earth's man-made or material-culture features, their characteristics and origins, as there is for its natural features. This, in part, may reflect the greater difficulty in classifying the less orderly array of man-induced features, as compared with those resulting from natural forces, since human beings are not governed by natural laws as are rivers and winds but by minds through which they are able to frustrate environment or adapt it to their needs. Man's acts are not entirely the result even of reason, for what he does is often influenced by moods, whims, and prejudices as well, so that the works of his hands may lack that orderliness and system characteristic of natural forms. This may help to explain why human geographies, unlike physical geographies, are rarely a classification and analysis of the elements of the subject, but rather are topical or regional treatments of associated cultural features.

A second reason for the more complete analysis and classification now available for the natural features as compared with the cultural

is that a number of specialized earth sciences have been at work on the problem of analyzing and classifying physical phenomena. Geology and geomorphology on the nature and distribution of earth materials and landforms, pedology on soils, meteorology and climatology on atmospheric conditions, biology on plant and animal distributions—each of these sciences has aided geography by providing it with basic materials on a particular phase of the physical earth. There has been no equivalent contribution to human geography from the various social sciences.

730. Purpose of Classification and Analysis of the Elements of Human Geography. It is immediately noticeable that the size of Part Two of this book dealing with the cultural elements is by no means equal to that of Part One that sets forth the natural elements. *This discrepancy between the sizes of Parts One and Two in no way indicates the authors' concept of the relative importance of the natural and cultural elements in geography* (see Preface). It chiefly reflects a fundamental contrast in the nature of the two groups of elements and of the materials bearing on the genesis and distribution of them. There are clearly defined world patterns in *types* of climate, soil, and native vegetation, and it is this fact that makes possible a relatively complete analysis of the distributional aspects of those natural elements. But, as pointed out in the Preface, world patterns of *types* are not so clear for settlements, population, manufacturing, or even for agriculture. In these elements there is much greater regional individuality, and as a consequence less in the way of generalized types which are repeated on the several continents. Any discussion of the cultural elements, therefore, is compelled to deal more with particular instances and regions than with types that are world wide in scope. Such a discussion does not warrant the same elaboration as one that is focused upon world types.

The discussion of the more important elements of human geography, included within the following chapters, attempts to introduce the beginner in geography to the general content of that field. In brief fashion it brings to his attention the more important groups of features inscribed by human beings upon the regions that they occupy. It is suggestive of the kinds of things, along with others of a physical nature, that one would observe and record on a map or in a notebook if he were making a geographic study of a region. No attempt is made to describe the human geography for the whole earth or for any part of it. The emphasis is upon *types* of land use and of material culture rather than upon a complete covering of the field of human geography. Nor has it been felt necessary to be consistent and logical in treating all the various forms of land use and their associated cultural features. For example, the extractive economies such as mining, hunting, fishing, trapping, and logging are not analyzed in separate chapters of Part Two as are agriculture and manufacturing. Significant comments on these less important economies, however, are included in certain chapters of Part One, especially Chap. 22 on Water Resources, Chap. 23 on The Biotic Resource, and Chaps. 26 and 27 dealing with economic minerals.

CHAPTER 28: *Population*

731. To the cultural features of the earth's regions man has a dual relationship: (*a*) collectively the people living on the earth's surface and occupying its regions are themselves one of the cultural elements and (*b*) man is also the originator, designer, and fashioner of all that great assemblage of features that results from his living on and utilizing the earth. No doubt it is the second of these relationships that gives man his principal geographic significance. The total portion of the earth's surface actually occupied by the bodies of human beings is insignificantly small, so that man himself usually is not a very conspicuous item on the planet. In terms of mass and areal extensiveness, the work of his hands is ever so much more dominant in the geographic scene than is the creator himself. Van Loon, in his popular book on geography, emphasizes this relative insignificance of the quantity aspect of human life when he shows that the earth's more than 2,000,000,000 inhabitants could all be put into a single large cubical box measuring $\frac{1}{2}$ mile on a side. Or, allowing each person 6 sq. ft. to stand on, the planet's total population would not occupy more than 450 square miles, which is about two-thirds the size of an average Wisconsin county. But in spite of the fact that human beings cover such a microscopic portion of the earth's surface, Brunhes, a famous French geographer, states that the two most important maps for all human geography are (*a*) the map of men or population and (*b*) the map of rainfall. For where human life is abundant, features of material culture are likely to be also.

It needs to be emphasized that geographers are not primarily concerned with groups of men or population from ethnographic, historical, social, political, or economic points of view but rather with their *spatial*, or *distributional*, aspects as expressed in terms of several closely related items, *viz*., (*a*) numbers, (*b*) density, (*c*) distribution patterns, and (*d*) movements. From these facts relating to numbers, densities, distributions, and movements of population, however, stem problems of momentous social, economic, and political consequences in which the geographer has primary interest.

The concepts of numbers, densities, and distribution as applied to population are much interrelated. It is difficult to think in terms of one without at the same time being conscious of the others. But, on the other hand, neither are the concepts synonymous, and so, in order to emphasize the distinctiveness of each, they are discussed separately.

1. Numbers and Distribution Patterns

732. Numbers of People. That there are on this earth approximately 2,250,000,000 people is probably the most basic of all statistical facts. Compared with it, data on area of cultivated land, tons of coal mined, or number of automobiles manufactured are in the nature of embroideries. Of these 2,250,000,000 people occupying the earth, over one-half are in Asia, one-quarter in Europe, and approximately 8, 7, and 4 per cent in North America, Africa, and South America. Among individual countries China leads with over one-fifth of the whole earth's population, while India comes next with nearly as many. Far below these two Asiatic countries come Soviet Russia and the United States, to be followed in turn by

Japan, Germany, the United Kingdom, Italy, and France.

Population Statistics
(Estimated for 1946)*

Continents	
Asia	1,187,000,000†
Europe	575,000,000‡
North America	203,000,000
Africa	173,000,000
South America	101,000,000
Oceania	12,000,000
Selected Countries	
China	430,000,000
India and Pakistan	414,000,000
Soviet Russia	193,000,000
United States	143,000,000
Japan	76,000,000
Germany	67,000,000
The United Kingdom	50,000,000
Italy	46,000,000
France	41,000,000

* World Population Estimates. *O.I.R. Report* 4192, Mar. 1, 1947, U.S. Department of State.
† Exclusive of Soviet Russia.
‡ Includes all of Soviet Russia.

The concept of numbers of people is an important one geographically, for there is usually a direct relationship between number of people in a country or region and the kind and intensity of land use prevailing there. But the simple concept of numbers becomes ever so much more important as an index of land use when it is supplemented by two other types of population facts. (*a*) The first of these involves the stage of agricultural and economic development of a people, their horsepower equipment, mental endowments, degree of health, cultural heritage, inhibitions, ambitions, and the like. A smaller number of energetic, ambitious people utilizing mechanical power may very well do more work and more completely modify the earth's surface than a larger population living on a lower plane of civilization. (*b*) A second supplementary item of importance is the trend of population, *i.e.*, whether there is growth, stagnation, or decline. Any treatment of population needs to be dynamic rather than static, for the rate of growth or decline of a nation's population greatly affects its wants, institutions, and arts.

733. *Contrasts in the Cultural and Economic Well-being of Populations.* It is clearly recognized that great differences exist in the civilization of the various peoples of the earth. There are parts of the earth whose population we speak of as being advanced and progressive, and there are others that are called backward and retarded. Important regional contrasts of a geographic character grow out of these differences in cultural and economic advancement. Ellsworth Huntington has attempted to show the world distribution of this elusive thing called civilization.[1] His map (Fig. 377) shows two major centers, one in northwestern Europe and the other in northern and eastern United States, with smaller centers in Pacific Coast United States, southeastern Australia, and New Zealand. The regions of low-scale civilization on Huntington's map are coincident with areas of unsolved climatic problems—(1) the cold regions of the subarctic and tundra, (2) the wet tropics, and (3) the dry lands. Although one may question the validity of certain distributional facts shown on the map, it does nevertheless represent in a general way what an Occidental would probably consider to be the broad distribution pattern of the elements of *western* civilization. A Chinese or a Hindu might not agree that it represented civilization in general.

The question may well be raised relative to what causes these great differences in stages of civilization among the world's population, which in turn result in contrasts in kind and degree of land use. Some would argue that, to a degree at least, it represents fundamental differences in racial potentialities; that the regions of highest civilization are those occupied by the most virile races possessed of physical and mental qualities that foreordained that they were to be the world's leaders. Of this type of philosophy the leaders of Nazi Germany have been the most ardent recent advocates. Anthropologists and psychologists are of the opinion, however, that there is no scientific basis for this doctrine of superior and inferior races. Up to the present time no reliable evidence is available that shows

[1] Ellsworth Huntington. "Civilization and Climate." 3d ed., pp. 240–274. Yale University Press, New Haven, 1924.

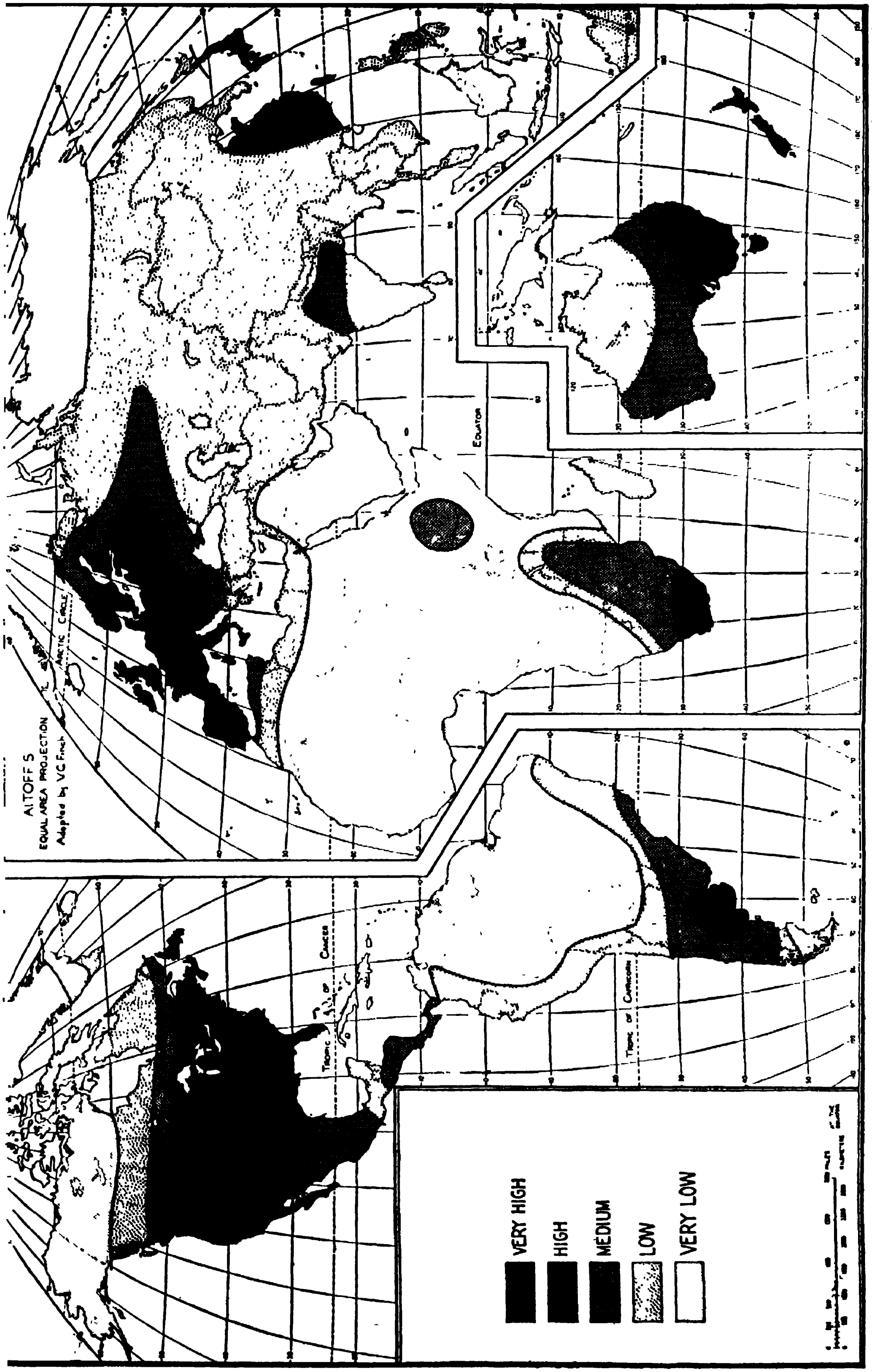


Fig. 377. Distribution of civilization according to Ellsworth Huntington.

inherent psychological and mental differences that distinguish the races fundamentally.

Huntington believes that climate, through its effects upon health and energy, is one of the most important factors having to do with regional variations in civilization.[1] It is only fair to say that many scientists discount his findings. According to Huntington three conditions of climate, (*a*) temperature, (*b*) humidity, and (*c*) variability, are of greatest importance in affecting health and energy. The ideal climate for human progress may be summed up as follows: (*a*) an average annual temperature that ranges from somewhat below 40 for the coldest month to nearly 70 in the warmest month (*b*) a relative humidity that is moderately high, except in hot weather, and rainfall at all seasons; and (*c*) a constant succession of cyclonic storms bringing frequent moderate changes in temperature. Huntington has constructed a map showing world distribution of climatic energy, and there is a close correspondence of this map with the one showing distribution of civilization (Fig. 378). He believes this coincidence between his maps of civilization and climate to be one of cause and effect, but here again there are many doubters.

Fairgrieve[2] and others have pointed out that cultural history, in other words, civilization, is the story of man's increasing control over energy. From this point of view a map of distribution of civilization is to be explained in terms of control and utilization of energy. The Industrial Revolution with its emphasis upon the use of mechanical power marks a great dividing line in history, and the parts of the world now generally recognized as most advanced are those which have made the greatest use of inanimate energy. The United States and Europe today are utilizing by far the largest amount of the world's mechanical energy and doing a disproportionate share of the world's work. It is estimated that the United States alone has an energy output from coal, oil, natural gas, and water power amounting to over half the world's total and is doing half the world's work.

[1] *Ibid.* Pp. 291–314, 387–411.

[2] James Fairgrieve. "Geography and World Power." 2d ed., p. 3. E. P. Dutton & Company, Inc., New York, 1921.

734. Growth and Trends in Population. One writer has compared the growth of the earth's population to a long thin powder fuse that burns slowly and haltingly until it finally reaches the charge and then explodes. Throughout 99 per cent of human history population remained extremely sparse and grew slowly, if at all. The rate of increase quickened somewhat a millenium or so ago when mankind graduated from an economy of fishing, hunting, and gathering and began to plant and harvest, to domesticate animals, and to fabricate pottery and textiles. The first real burst in population growth, however, the explosion at the end of the fuse, was coincident with the latest epoch in human progress—the Industrial Revolution (Fig. 379). This involved not merely technological advances but associated economic, social, and political changes as well. Three centuries ago the world witnessed what, by present rates of growth, appears almost a stationary population. This was the result of a high death rate nearly canceling out the effects of a high birth rate. Probably half the children died before reaching ten; 50 per cent of the population was under twenty; old people were few; the waste of life was colossal.

The Industrial Revolution began in Europe, and from there its influence spread round the world. The effects upon population growth were almost phenomenal, for it initiated an acceleration of population growth that, considering the earth as a whole, has continued for three centuries and down to the present time. The annual per cent of growth was only 0.29 in 1750; but 0.44 by 1800; 0.51 in 1850; 0.63 in 1900; and 0.75 in 1940; and 0.87 in 1948. Since the growth of world population is determined only by two factors, births and deaths, the unprecedented acceleration contemporaneous with the Industrial Revolution must be explainable in terms of these two factors. All evidence points to declining mortality as the principal cause. This began, at first slowly and gradually, as a result of a more abundant, regular, and varied food supply, which resulted, in part, from improved

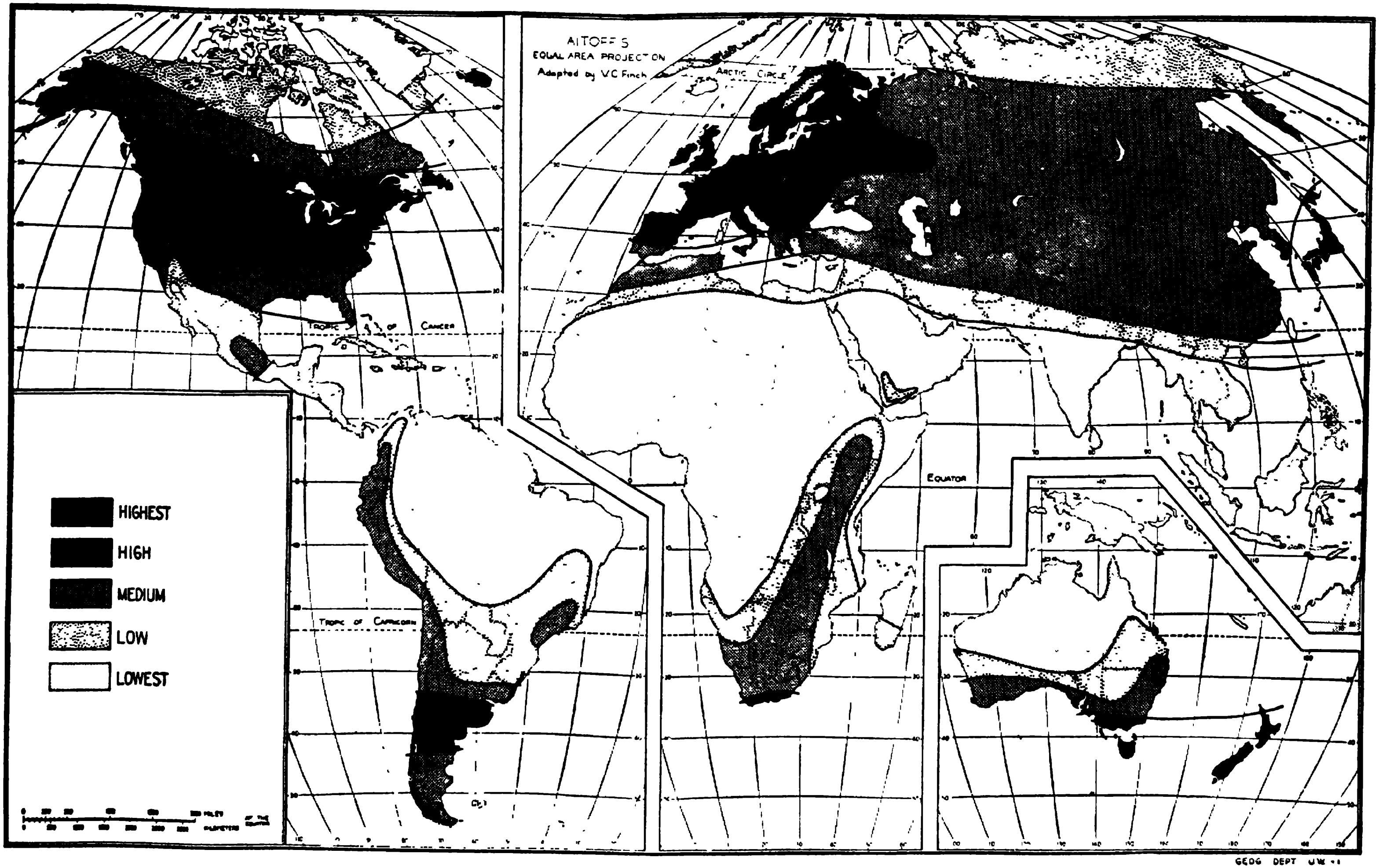


Fig. 378. Distribution of climatic energy according to Ellsworth Huntington. The density of shading is roughly proportional to the degree of climatic energy.

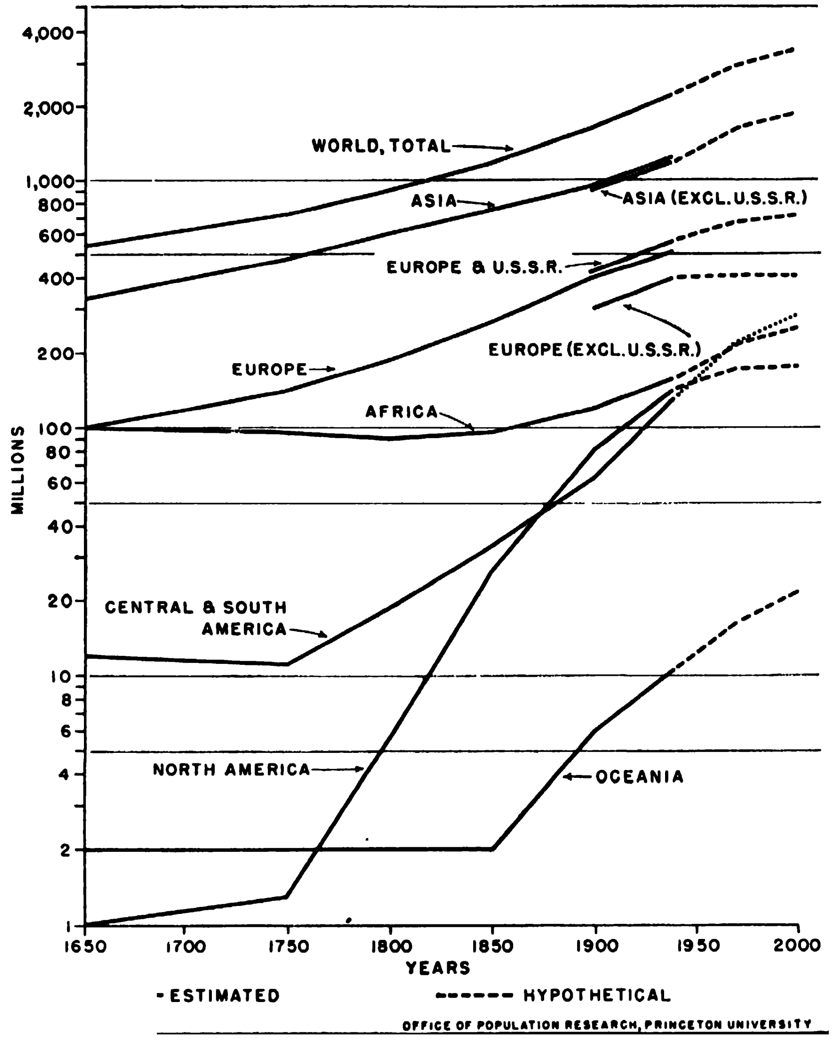


Fig. 379. Estimated population of the world and its continental subdivisions from 1650 to 2000 A.D. (*From Annals of the American Academy of Political and Social Science. Chart prepared by the Office of Population Research, Princeton University.*)

agricultural techniques, but even more, probably, from better transportation, which in turn stimulated commerce and small-scale industry. From this, commercial agriculture had its beginnings. Expanding ocean transportation carried the new agricultural techniques of Europe to new lands and fertile soils overseas, whose surplus produce shortly began to stream back to Europe. Each improvement in one part of the system reacted to improve all other parts, and the total effect was to reduce famine, undernourishment, and susceptibility to disease, and with these the death rate. The effects of scientific medicine and public sanitation were not felt until a later date, largely after the mid-nineteenth century, but these safeguards when they did arrive had a remarkable effect on lowering still further a mortality rate already greatly reduced.

735. Differential Rates of Population Growth. Although population growth for the world as a whole has been markedly accelerated during the past 200 years, the rates have shown striking differences for various peoples and re-

gions. Europe, for example, which originated the industrial and demographic revolution felt its effects first, so that it was the European peoples who increased at a much more rapid rate than the others. Within three centuries Europeans multiplied seven times while the rest of the world's population by contrast increased only three times. In 1650 they represented only 18 per cent of the earth's population; in 1933, 35 per cent.

This numerical expansion was accompanied by a vast geographical expansion as European settlers moved into new and sparsely populated lands which they discovered. Between 1846 and 1932 more than 50 million emigrated to frontier lands overseas. Thus, European stock, and with it European culture, were transplanted to the far corners of the earth—North and South America, Australia, New Zealand, North and South Africa, Siberia. Applying their advanced techniques to new and fertile soils the European settlers were able to produce such an abundance of food and agricultural raw materials that huge export surpluses became available for the mother countries. In regions already densely populated, such as eastern and southeastern Asia, the emigrating Europeans were able to achieve political and economic domination even though their own numbers remained relatively small. Using their own skills and their own capital, and exploiting the abundant native labor, they set up commercial plantation agriculture in fertile and strategic areas. The products as well as the profits from these plantation ventures went largely to Europe. The native peoples reaped relatively little economic advantage from being associated with the world economy, although certain elements of European culture such as medical science, public sanitation, improved transportation, and scientific agriculture had the effect of reducing mortality rates.

But while industrialization and commercialization, attended by a lifting of the general standard of living and a decline in mortality, characteristically result *at first* in an accelerated population growth, these same processes have within them the seeds of population retardation and eventual decline at a later stage. We must conclude that industrialization, with its accompanying concentration of people in cities, furnishes new and compelling motives for the control of births. Among rural peoples, especially in regions of subsistence agriculture, large families are looked upon as an economic asset; in a competitive urban society they are viewed as a handicap. Mechanization brings with it the danger of rapid changes and of loss of economic security, which make the rearing of large families seem less desirable. Moreover, the spread of education among the masses has roused them from a satisfaction with a life largely given to eating and bearing children to an attitude that demands other values. The result has been that maturing industrial societies have applied the same scientific approach to a limitation of births that they did at an earlier period to a reduction of mortality. For example, the birth rate for the white population in the United States, which was estimated at 55 per 1,000 persons in 1800, had declined to 30 by 1900, and to about 18 by 1940. The average annual rate of increase of 2.36 for the period between 1850 and 1900 was four times greater than the average for the world as a whole. Yet in recent decades the reproduction rate has declined so greatly that for the first time in history it fell below the replacement level in the period just prior to 1940. Similarly, in western and northern Europe birth rates have been halved between 1880 and 1935. Already in what were once the earth's fastest growing areas, on either side of the North Atlantic Ocean, the population has approached an almost static condition. Actual declines may be expected in some countries of western Europe within the next decade or two. What appears evident is that there are two phases in the normal population cycle of an industrial urban society—an earlier one of rapid growth and a later one of slower growth, with eventual equilibrium or even decline. Two of the three world centers of population, that in North America and western Europe, are already in the later or advanced stage of the population cycle (Figs. 380 and 381).

Of world importance is the fact that the third and largest of the earth's population clusters, by

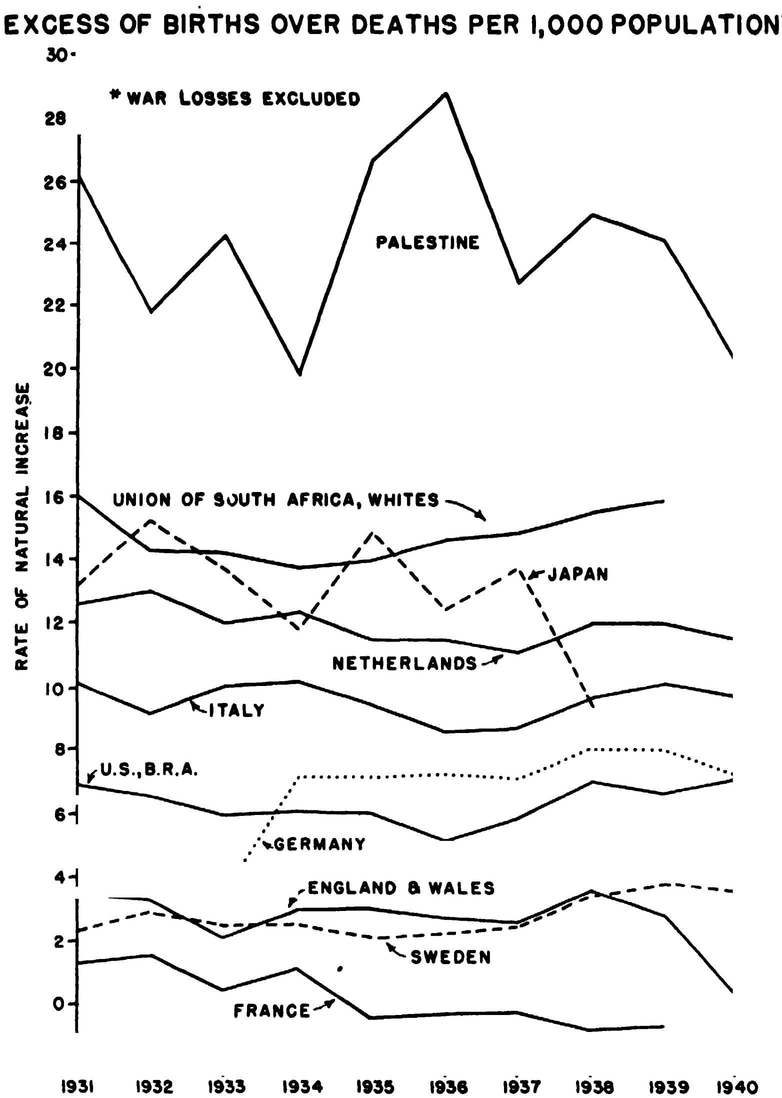


Fig. 380. (*From Population Index. Chart prepared by the Office of Population Research, Princeton University.*)

contrast, is just at the beginning of the population cycle. Eastern and southeastern Asia with one half the world's people is still largely in the pre-industrial era. It somewhat resembles Europe and the United States of a century or two ago, before rapid industrialization and urbanization of these regions began. Within the populous Orient, birth rates and death rates are still very high and uncontrolled. Death rates vary greatly depending upon the prevalence of famine and pestilence. For this reason it is difficult to forecast future population growth. But if it can be supposed that the Orient will reasonably duplicate the population history of Europe and the United States, then, given certain conditions of improved sanitation and food supply, it is possible to estimate the trends within the next few decades. It seems likely that the Orient will shortly, because of improved agriculture, public sanitation, better medical facilities, and increasing westernization, enter a period of decreasing mortality. In such a region of predominantly rural people and with social and religious attitudes what they are, there is small hope for

a similar decrease in birth rates. The result will be a large annual increment of population and consequently a greatly accelerated growth. This is the first stage of the population cycle. But herein lies the marked contrast between Europe and North America on one hand and Asia on the other as each entered this stage of rapid increase—the two Occidental regions started from a small population base, while the Orient begins with nearly half the world's people. Anything like the same *rate* of increase in Asia as occurred in the West will result in much larger total numbers. That this is not unthinkable is illustrated by Japan, the one political unit in the Far East that felt Western influence most, where population doubled in half a century. Or the case of India may be cited, where as a result of recent famine and epidemic control, 50 million were added to the population in one decade. This is a third of the total population of the United States and greater than those of Britain, France, or Italy. What seems reasonably clear is that a large part of the world's population increase in the next half century will be in the Far East and to a smaller extent in eastern Europe, especially Russia, where birth rates are also high (Figs. 380 and 381).

736. Differential Population Growth and World Peace. The difference in population growth among regions and countries, and the resulting unequal pressures of men upon resources, is one of the basic causes for war. The actual lack, or even *felt* lack, of adequate resources for supporting a rapidly growing people at a desired standard of living may cause a nation to try to right what it considers inequalities by resorting to armed conflict. What a person or a nation *needs* is always a matter of judgment and consequently a relative thing. The land and resources considered necessary by a feudal and isolated Japan in 1860, with a static population of 30 million or less, were very different from those *felt* to be essential for a growing industrialized nation of 70 million in 1940. It is doubtful whether Germany would have challenged France three times within 75 years if her population had not been a rapidly

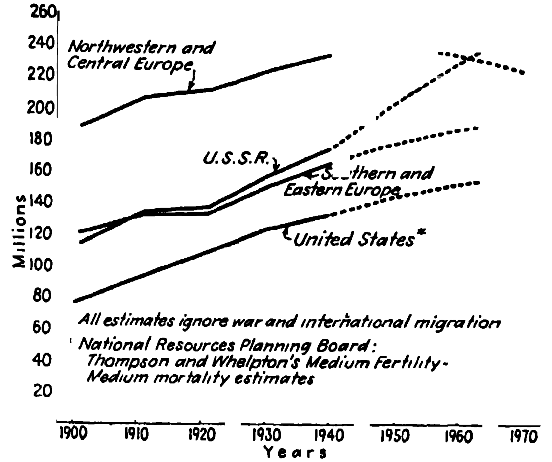


Fig. 381. Actual population trends 1900 to 1940, projected to 1970. (*From Population Index. Chart prepared by the Office of Population Research, Princeton University.*)

growing one while that of France was relatively stationary. In view of the enormous increase in number of people that is already occurring, and will probably continue to occur, in Asia one cannot help feeling apprehensive concerning the threats to world peace that such an increase entails. The upward surge of population in the Orient, combined with expansion of industrial output and of military potential, is bound to make that part of the world more conscious of its relatively low living standards and the fearful pressure of men upon resources. There is always the possibility that one or more of the political units of the Far East, because of a *felt* discrimination against it in the matter of the use of land and resources, may, like Japan, be tempted to try to take what it believes it needs and deserves.

POPULATION-DISTRIBUTION PATTERNS

737. Patterns of the First Order, or World Patterns. Human beings are widely dispersed over the land surface of the earth, and there are only a few extensive areas, such as Antarctica, the Greenland Ice Cap, and perhaps a few of the worst deserts, which are entirely devoid of permanent human settlements. On the other hand, while dispersion of people is widespread, it is equally true that they are far from being equably spread even within the occupied regions.

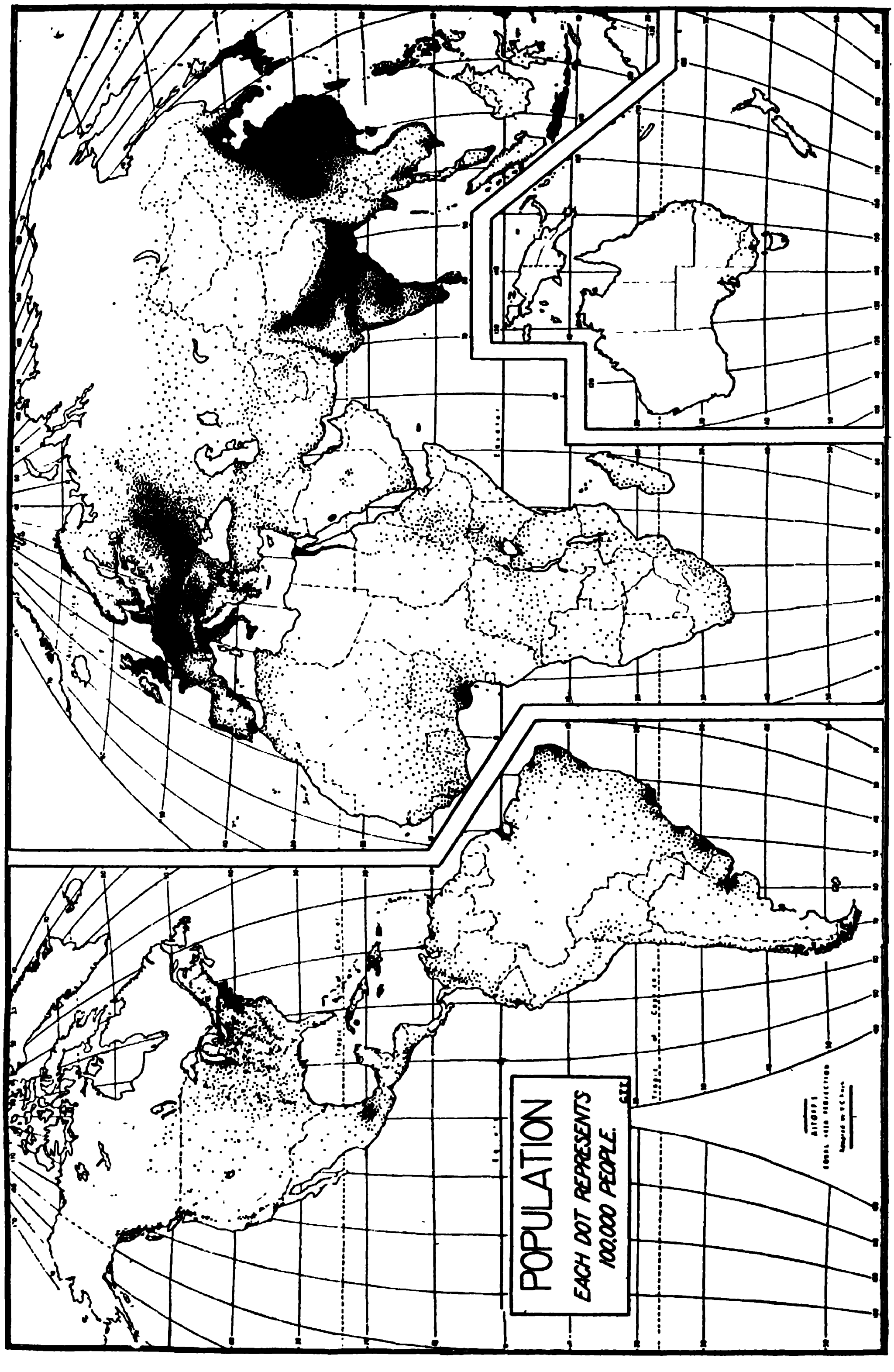


Fig. 382. Distribution pattern of world population.

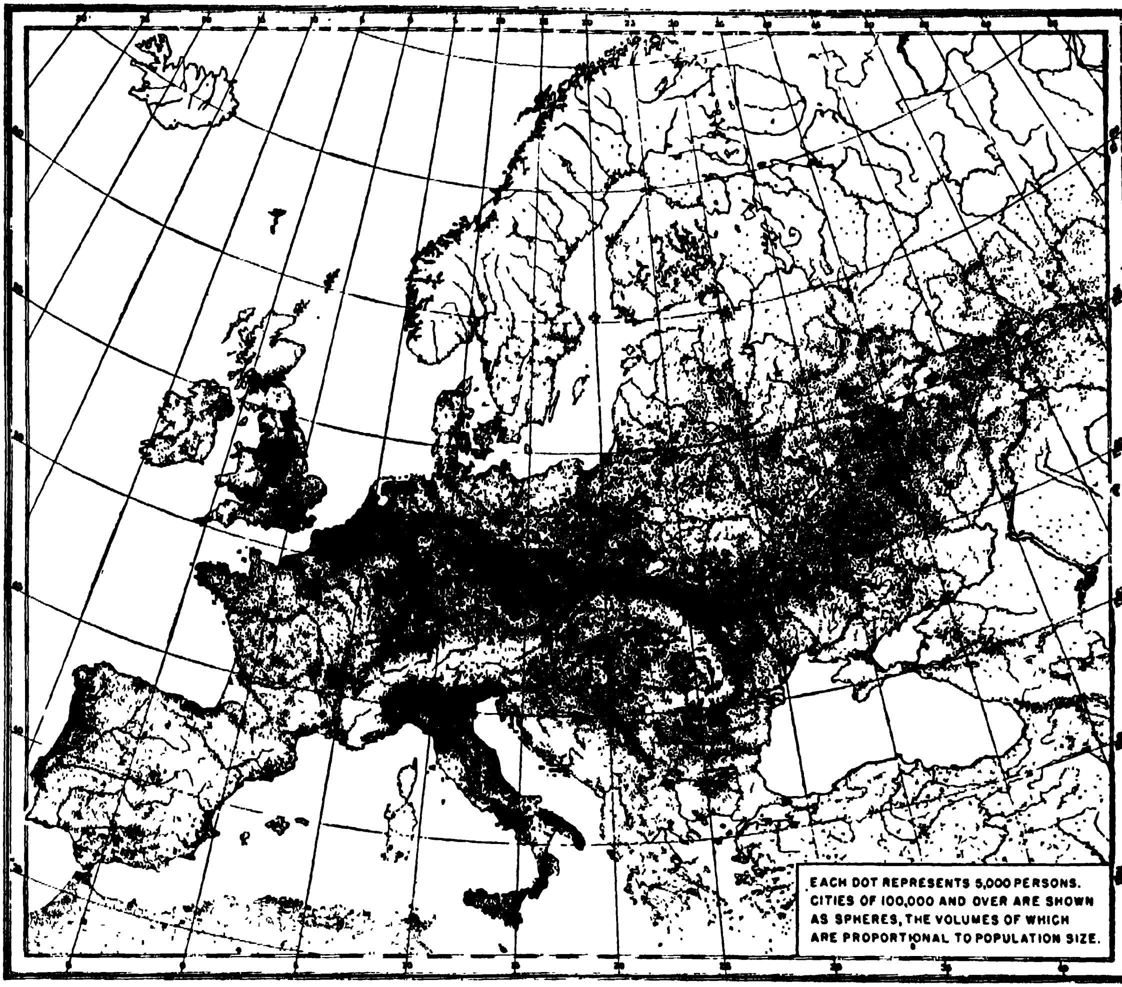


Fig. 382*A*. Distribution of population in Europe. (*Adapted from "Sydow-Wagners Methodischer Schulatlas." Previously, published in Dudley Kirk, "Europe's Population in the Interwar Years."*)

Roughly four-fifths of the earth's population is concentrated in three great clusters of subcontinental size (Fig. 382). On a map of world population the most conspicuous cluster is the one in eastern and southeastern Asia, which contains about one-half the earth's people, or over one billion. The most populous political units within this Far Eastern region are China with 400 to 500 million; India, 400 million; Japan, 81 million; and Java, 50 million. The second major world cluster of population is in Europe, which embraces about one-quarter of the earth's people, or over 500 million. Central and eastern Anglo-America (United States and Canada) comprising the third cluster is much smaller than the other two, for within it resides only about one-fifteenth of the world's population.

Except for parts of south Asia, more particularly southern India and Java, the population of the three great world clusters is located almost exclusively in the middle latitudes of the Northern Hemisphere. Rather definite limits appear to be set to the expansion of the well-populated areas by low summer temperatures and short growing season on the north and by increasing aridity chiefly toward the interior.

The three population concentrations pair off in other important respects as well. Thus, the American center developed as a result of a budding off from Europe and consequently bears

the stamp of European culture and its features of economic development. Commercial and regionally specialized agriculture, factory industry, large foreign and domestic trade, and efficient transportation systems are characteristic of the Atlantic Basin centers. These two are far advanced in a machine-age civilization; the Industrial Revolution, construed broadly as involving economic, social and political, as well as technological changes, has here transformed the ways of living. On the whole, and of course relatively, individual wealth is great; living standards are high; regional specialization is well developed; cities, the offspring of industry and commerce, are numerous; and human life is valued highly as evidenced by the relatively low mortality rates and the fertility rates as well.

By contrast, the ancient world still exists to a large degree in the more populous Far Eastern center. This is a region of poverty-stricken peasant farmers engaged in intensive subsistence agriculture. Population presses closely upon the food supply; poverty and disease are omnipresent; depressingly high birth rates and high death rates manifest a people wasteful of energy in the eternal chain of reproduction. Sickness, malnutrition, and preoccupation with death further exhaust vitality. The Industrial Revolution has left relatively untouched most of this Oriental region; factory industry and trade are meagerly developed; cities are relatively few; communications for the most part are crude and inefficient. Both in forms of culture and in stage of economic development the Far East stands as the antithesis of those two population centers bordering the Atlantic Basin. Before the Second World War, Japan was the single political unit within the Far East which has pushed its head well above the dead level of that region's stagnation.

738. Types of Meagerly Settled Lands. At the opposite extreme from the three great subcontinental clusters of dense population just described are the lands of the earth which are relatively empty of people. With a few exceptions, and excluding areas of high altitude and rugged terrain, these are regions of serious climatic handicaps. On the map of world population the most extensive empty spot is the Arctic borderlands—the subarctic and tundra of North America and Eurasia. Along the southern margins of the subarctic lands the frontier of settlement is advancing only slowly and irregularly. At present the relatively few settlers in the subarctic are chiefly engaged in such extractive economies as trapping, mining, and logging. The total landscape is one composed chiefly of natural features; man has left but faint imprint. In productive capacity the subarctic lands are basically handicapped by a niggardly climate whose cool summers and short frost-free season set definite and low limits upon agricultural development. Add to this two other discouraging features: (*a*) the extensive development of podzols, the earth's most impoverished mature soil; and (*b*) the widespread occurrence of lake, swamp, and generally poor drainage, resulting in part from recent continental glaciation. Such a total environment is likely to frustrate any large-scale immigration of agricultural settlers from more populous regions, even those where crowding is already serious.

A second of the earth's thinly populated realms is the wet tropics: the regions of tropical rainforest and savanna climates. These hot regions are by no means so uniformly empty as are the subarctic lands. For some unknown reason the tropical forest and grasslands of the New World are far emptier than those of the Old. In a few instances like Java, southern India, and Puerto Rico dense native populations are at present being supported within the wet tropics. But there remain very extensive areas within the tropics of Latin America, Africa, and southeastern Asia and adjacent archipelagoes in which population is sparse enough to suggest the possibility of large-scale immigration.

Unlike the subarctic lands these tropical latitudes bask in a prolific climate. Constant heat the year round and moderate to abundant rainfall provide a climatic environment in which plant life reaches its maximum growth. Since plants are the ultimate source of food for human beings, this would suggest a climate with maximum potentialities for food production. But these hot rainy climates which are so prolific in

vegetation productively are widely believed to have injurious effects upon human beings. On the whole, history has given the tropics a bad name. There is no doubt that the endemic diseases of the tropics such as malaria, yellow fever, sleeping sickness, and others have been scourges of the first order. Within recent decades, however, great strides have occurred in the discovery of causes for many tropical diseases and likewise of preventives and cures for some. The result has been a greatly increased optimism concerning the possibility of healthful living in the low latitudes.[1] Whether there is direct injurious effect of tropical heat and humidity upon tropical residents, quite apart from that resulting from disease, is a disputed question which only medical science can resolve.

But if the tropical climate is bountiful, the low-grade red and yellow soils offer a serious counterbalance, particularly as it applies to the growing of shallow-rooted crops. The strong leaching effect of the abundant and warm rains leaves most of the tropical soils deficient in most soluble mineral plant foods and in organic matter as well. Only a very few years of crop growth is required to exhaust the soil. This is a primary reason for the shifting or migratory agriculture so characteristic of the wet tropics. Low-grade soils appear to be one of the serious obstacles to widespread development of agriculture in the low latitudes.

The third of the earth's thinly peopled realms is that with dry climates. It is a misfortune of the first order that such an unproductive climate should be so widespread, occupying over a quarter of the earth's land area. In dry lands not only is rainfall insufficient for most crops, but it is also undependable, varying widely from year to year. Any expansion of agricultural settlement into the dry lands must be the result of (*a*) an increased use of irrigation, or (*b*) the further development and greater use of drought-resisting crops. Neither of these methods appears to hold much promise for opening up extensive areas in the deserts and steppes for potential agricultural settlers. The sparse native grasses of the dry lands provide the basis for a grazing industry, but grazing is capable of supporting only a meager population.

739. *Will the World Pattern of Population Distribution Change?* To an unusual degree the present world pattern of population distribution reflects the productive capacities of the earth's great regions. In other words, the people of the earth are where they belong in terms of natural resources and equipment and taking into consideration their present standards of living.[2] The world has been pretty well explored in terms of productive capacity, and marked shifts in population numbers and densities growing out of the occupation of now thinly peopled areas are hardly to be expected. Great mineral discoveries such as have characterized the last few centuries are unlikely. In a few places, such as parts of South America, for example, extensive areas of land are held out of full settlement by the large size of the land holdings. Some parts of dry Asia fit for agriculture are prevented from being so used by their present utilization by pastoral peoples. A few relocations of population may result from (*a*) discovery of new crops and the improvement of others through plant-breeding methods, and (*b*) the extension of public hygiene, particularly in the wet tropics, where colonization seems to be partly, if not largely, a matter of health. Of all the earth's thinly peopled realms, it is the wet tropics which appear to have the greatest potentialities for supporting sizable increases in population.

So, although there are large areas of the earth still potentially available for human settlement, these are mainly of a marginal nature, often because of climatic handicaps. Such regions can be occupied only with considerable effort and at high cost so that settlement is discouraged. Thus, while the frontiers of settlement have not

[1] A. Grenfall Price. White Settlers in the Tropics. *Amer. Geog. Soc. Special Pub.* 23, 1939. See also Yearbook of Agriculture, 1941, pp. 237–261.

[2] Carl O. Sauer. The Prospect for Redistribution of Population. Chap. I of Isaiah Bowman (editor). "Limits of Land Settlement." Council on Foreign Relations, New York, 1937; Jan O. M. Broek. Climate and Future Settlement. "Climate and Man." Yearbook of Agriculture, 1941, pp. 227–236.

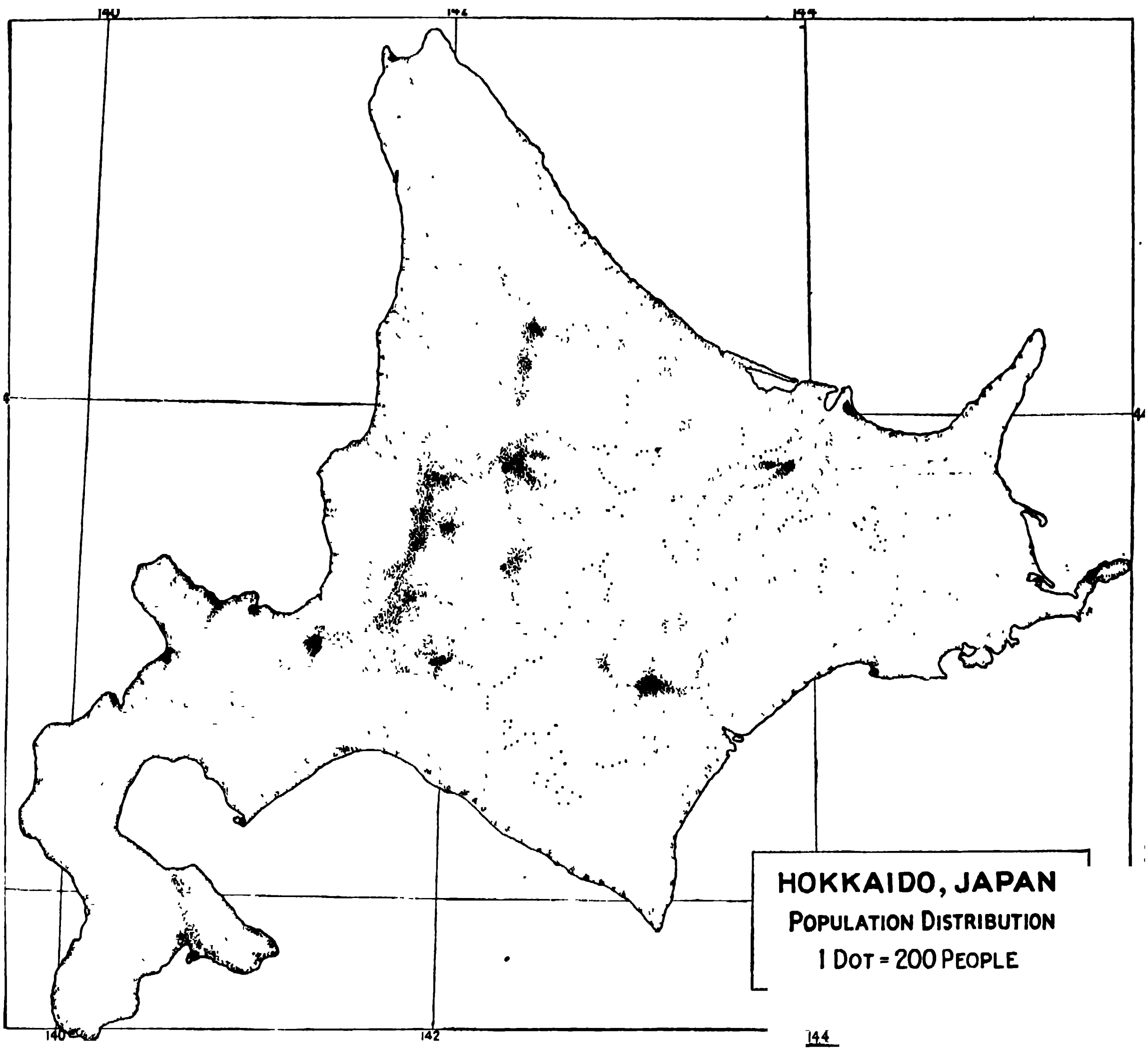


Fig. 383. Pattern and density features are both conspicuous. As in the whole Far East, population in this northern island of Japan is concentrated upon the plains of new alluvium.

become stagnant, their advance in the future will be much slower than has been true in the past.

740. Patterns of the Second Order. Asia. If the focus is sharpened somewhat, it is evident that within any large area of the earth there are lesser patterns of population distribution which are conspicuous and distinctive. Thus in southeastern Asia, which supports such a large percentage of the world's people, the spread of population is very uneven. Here it is a much fragmented or *clustered* pattern that is conspicuous, with a relatively small part of the total land area supporting a great majority of the people (Fig. 383). Almost knife-edge boundaries frequently appear to separate areas containing several hundred, or even thousand, persons per square mile from others which are almost barren of settlement. This markedly clustered pattern of population is closely associated with surface configuration and soil characteristics, for southeastern Asia is, in general, a hilly region with restricted lowlands composed of river alluvium. Moreover, the residual soils of the uplands are characteristically badly leached and of low fertility so that the fertile alluvial lowlands stand

out by contrast. The peasant farmers have tended to gravitate toward these alluvial lowlands, where soils are fertile and gentle slopes and abundant water, two items relatively necessary for the inundated rice crop, are easily available. The more difficult slope sites with thinner less fertile soils are avoided. In hilly Japan only 16 per cent of the land surface is actually cultivated. One might with great fitness describe the Orient as having an "alluvial civilization."

This concentration of agricultural effort on only the best land is explained in part by the large dependence upon hand labor and hand tools. It requires approximately 15 man days to spade an acre of land by hand, so that the farmer who depends entirely on his own muscles can cultivate only an acre or two of ground. Even those who have an ox or horse can plow at most only a few acres. Since it takes just as long to dig up and cultivate poor land as good land the oriental farmer is obliged, in order to feed his family, to put his efforts on the most productive soil. On anything else he would starve. In the United States on less productive lands the farm area is increased, and this greater area is operated through the use of more animal or motor power and the use of labor-saving machinery. But this adaptation the oriental farmer is incapable of making.

In Japan, which is much more highly industrialized and urbanized than the other political units of the Orient, the coincidence of population with fertile alluvial lowlands is unusually marked. In 1940 urban population amounted to about half the total. But the great metropolises have developed on the most extensive alluvial plains so that city and country people alike overcrowd the level lands. Since the lowlands are predominantly coastal in location, the result is a population which closely hugs the seaboard. It is not surprising that the Japanese are closely bound to the sea. For a people whose mode of living is closely adjusted to a subtropical environment the colder climates of the higher middle latitudes are less attractive, so that a great majority, of the nation's population is in that part of the country which lies south of the 37° parallel. Within this subtropical part of Japan there is a marked concentration of people in a long, thin irregular zone, more than 600 miles long, extending from Tokyo and Yokohama on the northeast, southwestward along the Pacific Coast to the Nagoya area and thence along the shores of the Inland Sea to northern Kyushu. Within this populous belt lie 50 per cent of the country's cities and three-quarters of its industrial workers, and in it were produced over 80 per cent of the manufactures. Here also are located the five ports which together handled 90 per cent of Japan's foreign trade. Within the hilly interior of the country, population clusters in a number of basinlike areas or exists in the form of long thin lines, dendritic in pattern, coincident with the river valleys.

China, with a fifth of the earth's people, 80 per cent of them rural, exhibits a very uneven distribution. If a line trending northeast-southwest is drawn from Yunnan in the southwest to northern Manchuria, it divides China into two very unlike population regions. Dry highland China to the west of the line with 2.2 million square miles of territory contains an estimated 15 to 20 million people, while humid China to the east with 1.8 million square miles probably has 400 to 450 million. Within humid China the great concentrations are coincident with the North China Plain (80,000,000), the Yangtze Valley (65,000,000) and the Basin of Szechwan (50,000,000). Within the hill lands a dendritic pattern of distribution is very conspicuous.

India's 400 million people, likewise, are crowded on to the fertile alluvium of the river valleys. It is estimated that in the neighborhood of one-half the total are in the Indo-Gangetic valley of northern India. Since the western part of this lowland is dry, densities are much higher in the humid Ganges part of the plain than in that portion drained by the Indus River. With increase in rainfall eastward, population likewise increases in the same direction, and reaches over 600 per square in the Ganges Delta. Hilly peninsular India shows many fewer people, the only really high densities being

coincident with the coastal deltas, particularly those on the east side (Fig. 387).

By contrast with India, China, and Japan, the peninsula of Further India (Burma, Siam, French Indo-China, Malaya) and the islands of the Indies contain relatively fewer people. Why this should be is not entirely clear. In part it may be associated with the stage of agricultural development, for while China, Japan, and parts of India have advanced to the plow-garden stage of growing irrigated rice, most of Further India still relies upon less efficient and less intensive natural inundation methods. Within Further India is repeated the same clustered pattern with a high degree of population concentration on the delta plains.

Among the islands of the East Indian archipelago only Java is densely populated. The Indonesian islands other than Java have populations which are well below the average of the Far East. Thus Java and Madura, which have only 7 per cent of the area of the Netherlands Indies, contain nearly 70 per cent of the total population. This unusual concentration of people in Java is related in part to the high fertility of the volcanic soils of that island. In part, also, it was the result of the Dutch finding here a large and tractable native labor supply for their plantation agriculture. The Javanese for centuries have been sedentary farmers versed in husbandry, while the other islands until recently were largely peopled by tribal groups still in the gathering-economy stage. Without doubt the fact that Java early became the center of Dutch civil and military control, and thus was the first to benefit from European agricultural methods and sanitation, had much to do with the disproportionate growth of population in that island.

Over dry central and western Asia population is concentrated in or near the highlands where water for irrigation is more abundant. In Siberia there is a marked focusing of the agricultural population on the east-west belt of fertile dark soils in western Siberia, lying between the subarctic taiga region on the north and the dry lands of the Aral-Caspian region to the south.

741. *Europe.* In western Europe as well, even on the lowlands, the clustered population pattern is conspicuous, although the boundaries of the clusters are usually not so sharp as in eastern Asia. This clotted pattern is particularly evident in Great Britain, where only 8 per cent of the population are farmers and 80 per cent are classed as urban. In that island six of the seven most conspicuous population clusters are industrial urban concentrations coincident with important coal fields (Fig. 334). Three of these are in central England flanking the Pennine uplands: the Lancashire node to the west with the two great metropolises of Manchester and Liverpool; the Yorkshire node to the east of the highlands containing Leeds, Bradford, and Sheffield; and the Midlands industrial center at the south end of the Pennines supporting Birmingham and Stoke. The Northumberland-Durham population node in northeastern coastal England, along the Tyne and Tees rivers, is supported by resources of both coal and iron. Here Newcastle, the most northerly of the great English cities, has developed. The Scottish population node, relatively coincident with the Scottish Lowland and its coal field, contains the great cities of Glasgow and Edinburgh. South Wales and its coal support the population clot of which Swansea and Cardiff are a part. The London center, the greatest of all, and containing about one-fifth the total population of Great Britain, is the striking exception to the general coincidence of population centers with coal, for the immediate London area lacks coal. Greater London, to be sure, is a manufacturing area of first rank, but its factories turn out goods of a kind which require less power and more labor and which are attracted by the great London market. Throughout its history London has been more famed as a port than as a factory town, while it is the political and financial capital of the nation as well. Most of Britain's industrial regions have their own ports which serve them more or less locally, but London, on the other hand, is the port for almost the whole of Britain and an entrepôt port for a more extensive area.

On the continent of Europe there is a con-

tinuous belt of extremely dense population oriented east-west along the fiftieth parallel from the North Sea and English Channel to the lower Dnepr (Dnieper) in Soviet Russia. This might be called the *European population axis*, and it is highly coincident with the urbanized industrial regions (Figs. 387 and 389). The belt broadens from east to west, and the density of population likewise increases in the same direction. It reaches its greatest density in the general vicinity of the lower Rhine, coincident with important coal and iron deposits and lying near the mouth of one of the world's great natural waterways (Fig. 382*A*). This maximum concentration of people in the general region of northwestern Germany, Holland, Belgium, and northern France is continued eastward in somewhat less intense form through southern and eastern Germany; northern Bohemia and Moravia in Czechoslovakia, southern Poland, and into the Ukraine of southern Soviet Russia. The nearly 200 million inhabitants of the Soviet Union are concentrated largely within the European part of the country west of the Ural Mountains. More precisely, it is within a long thin triangle, oriented east-west, the apexes of whose angles are at approximately Odessa and Leningrad in the southwest and northwest, and at Tomsk east of the Urals, that a very large part of the country's population, agricultural land, and industrial production are contained. This is the Soviet coreland. Throughout the length of the European population axis, which contains more than a fourth of the people of the continent, lie the most important coal basins of Europe, the power resources of which have aided the growth of numerous industrial cities (Fig. 382).

In Mediterranean Europe high population densities are found on a number of small isolated basins or delta plains, but these populations are based chiefly upon agriculture. Chief among these "islands" of population is the one occupying the large and relatively fertile Po Valley in Italy. Here both rural and urban population are present in great numbers, for this is Italy's most highly industrialized region and her focus of agricultural production as well. It thus becomes obvious that, although eastern Asia's population concentrations are composed of peasant agricultural peoples focused upon fertile alluvial plains, to a much larger degree western and central Europe's population is concentrated in commerical and industrial towns and cities grouped with respect to basic mineral resources, important routes of trade, or fertile plains producing raw materials and food.

742. *Anglo-America.* In the United States the most striking feature of population distribution is the contrast between the well-occupied eastern half, on the one hand, where the climate is humid and lowlands predominate, and the thinly peopled West, a region of general rainfall deficiency and one where highlands and rugged terrain are abundant (Fig. 382). Approximately 85 per cent of the country's inhabitants are located east of the 100th meridian. Over much of the eastern half of the country population is widely spread, and while there are contrasts in density, to be sure, a marked clotting or clustering is not so conspicuous. It is chiefly in the northeastern portion of the United States, north of the Ohio River and east of the Mississippi, which includes the nation's manufactural belt with its large city population, that clots of above-normal population density become more prominent (Fig. 384). Most conspicuous is the almost continuous belt of high density stretching along the Atlantic seaboard states from southern Maine to Maryland. This is coincident with the country's greatest manufacturing concentration, and the same region includes a large percentage of the great foreign-trade ports such as New York, Boston, Philadelphia, and Baltimore.

West of the Appalachians the clots of highest population density are fairly coincident with the industrial nodes along (*a*) the southern and southwestern shore of Lake Michigan, which includes Chicago and Milwaukee (*b*) the western and southern shore of Lake Erie, containing Detroit, Cleveland, Toledo, Buffalo, and Akron (*c*) the southern margins of Lake Ontario and the Mohawk Valley, where Rochester, Syracuse, Utica, and Schenectady are

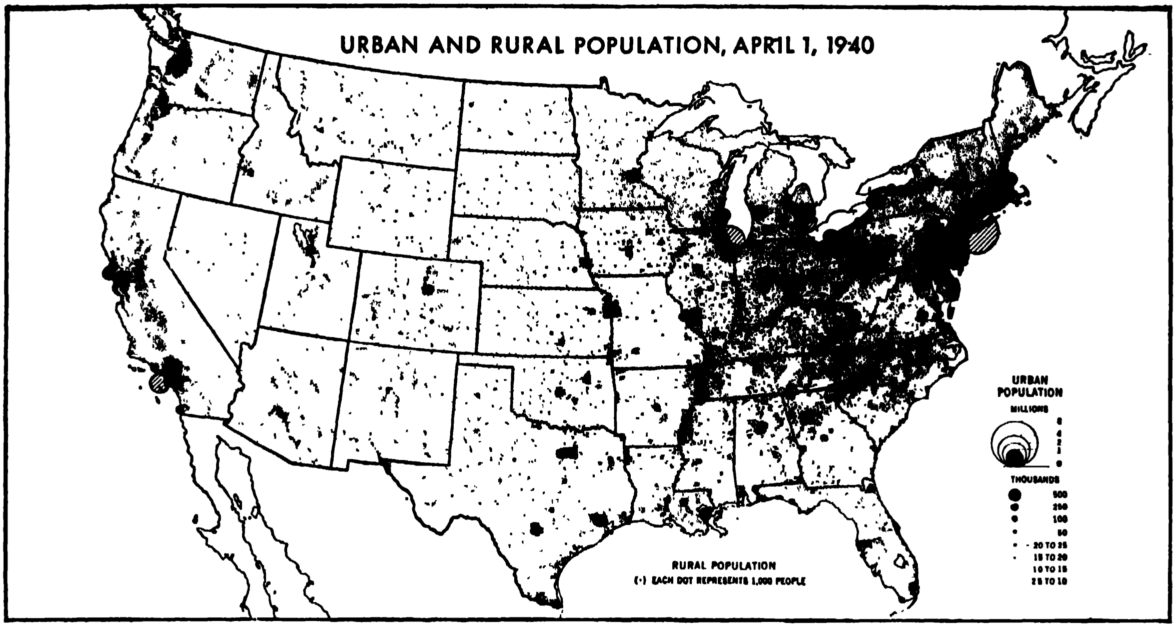


Fig. 384. (*U.S. Department of Agriculture.*)

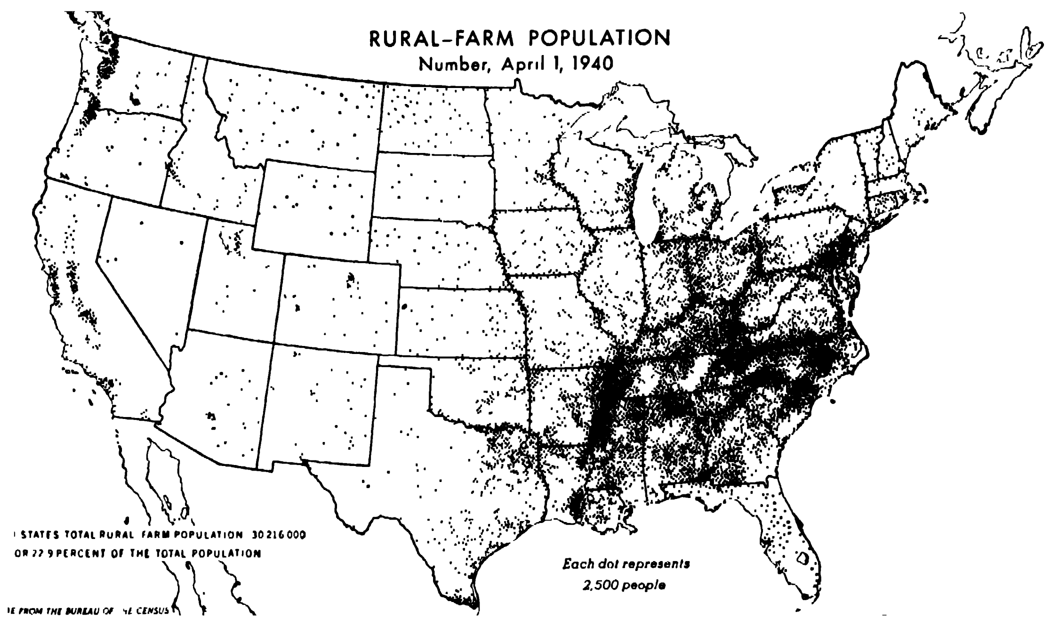


Fig. 385. Note the concentration in the southeastern part of the country. (*U.S. Department of Agriculture.*)

located; and (*d*) the upper Ohio Valley in western Pennsylvania and eastern Ohio, where Pittsburgh is the chief metropolis. Over eastern United States rural farm population is highest in the South where the two principal crops, cotton and corn, require large amounts of human and animal labor (Fig. 385).

West of the 100th meridian or thereabouts, in the dry and rugged West, population density averages only about 12 per square mile. This is to be compared with 45 per square mile for the country as a whole, 80 in the Middle West, and over 200 in the Northeast. In the West, also, the population pattern is one in which a

few spots of relatively high density are separated by extensive areas of very sparse settlement. Usually the spots of high density are associated with areas having supplies of water for irrigation—river valleys, piedmont alluvial plains, mountain basins—or localities of important mineral exploitation. Within the generally dry West it is the Pacific Coast states with their more humid and therefore productive climates, and their larger industrial and port cities, that show the largest population figures. Thus, in 1947 the three Pacific Coast states had a combined population of 13,626,000, while the eight mountain states to the east of these and including the territory east to the Great Plains had only 4,399,000 people. Moreover, the Pacific Coast states showed the largest percentage population increase (40 per cent) for the period 1940 to 1947 of any of the regional subdivisions of the country. Within the Pacific Coast states there are three principal groupings of population: (*a*) the Puget Sound–Willamette Valley center in Washington and Oregon, which supports such cities as Seattle, Portland, and Tacoma; (*b*) the Great California Valley and San Francisco Bay node with San Francisco and Oakland; and (*c*) a southern center occupying the smaller lowlands around and back of Los Angeles and San Diego.

Canada's 12 million people are markedly concentrated along the southern margin of the country, where the available agricultural lands are located. But the east-west belt of population along the international boundry is far from continuous, large areas of barren country tending to isolate the people into four or five distinct clusters. Chief of these is the one occupying the Ontario Peninsula and the St. Lawrence Valley. Other less important ones are (*a*) in the Maritime Provinces facing the Atlantic, (*b*) in the Prairie Provinces, and (*c*) in maritime southwestern British Columbia.

743. *Latin America, Australia, Africa.* In tropical Latin America, more especially Middle America, and South America north of the equator, population is markedly concentrated in the côoler uplands. Nearly two-thirds of Mexico's people live in the higher, cooler, and more humid southern portion of that country's central plateau. Mountain and plateau location tends to isolate the individual population clusters from each other so that anything like a national consciousness is difficult of achievement. Throughout South America the people tend to concentrate along the margins of the continent, leaving the interior relatively empty of settlement (Fig. 386). Dry southern Argentina and the interior wet tropical lowlands of the expanded northern part of the continent contain only a sprinkling of people. The margins of the continent are more attractive for settlement where the highlands provide an escape from tropical heat, as they do in Venezuela, Colombia, Ecuador, and eastern Brazil. Moreover, the ocean serves as a highway and provides what is the only efficient means of intercommunication for many important settlement areas. A pattern consisting of several distinct and relatively isolated centers of population is characteristic of eastern South America. In northeast Brazil the high density reflects the early importance of tropical agriculture when African slaves were used in great abundance. Farther south, the centers of population back of Rio de Janeiro and Santos, and including the upland metropolis of São Paulo, reflect an agricultural economy based upon such commercial crops as coffee and cotton. The middle-latitude settlement cluster on the plains of the Rio de la Plata in Argentina and Uruguay is associated with one of the world's great regions of surplus agricultural production and the ports of Buenos Aires, Montevideo, and Rosario that serve it.

Australia's 7,500,000 people are likewise marginal in location and concentrated chiefly along the subtropical southeastern seaboard. Much of interior and western Australia is too dry for agricultural land use, and the humid tropical climate of the northern part has likewise been a deterrent to settlement. In Africa population concentration is conspicuous (*a*) along the Mediterranean borderlands, (*b*) in the western Sudan and along the Guinea coast, (*c*) on the East African uplands including the Abyssinian Plateau, and (*d*) along the southern

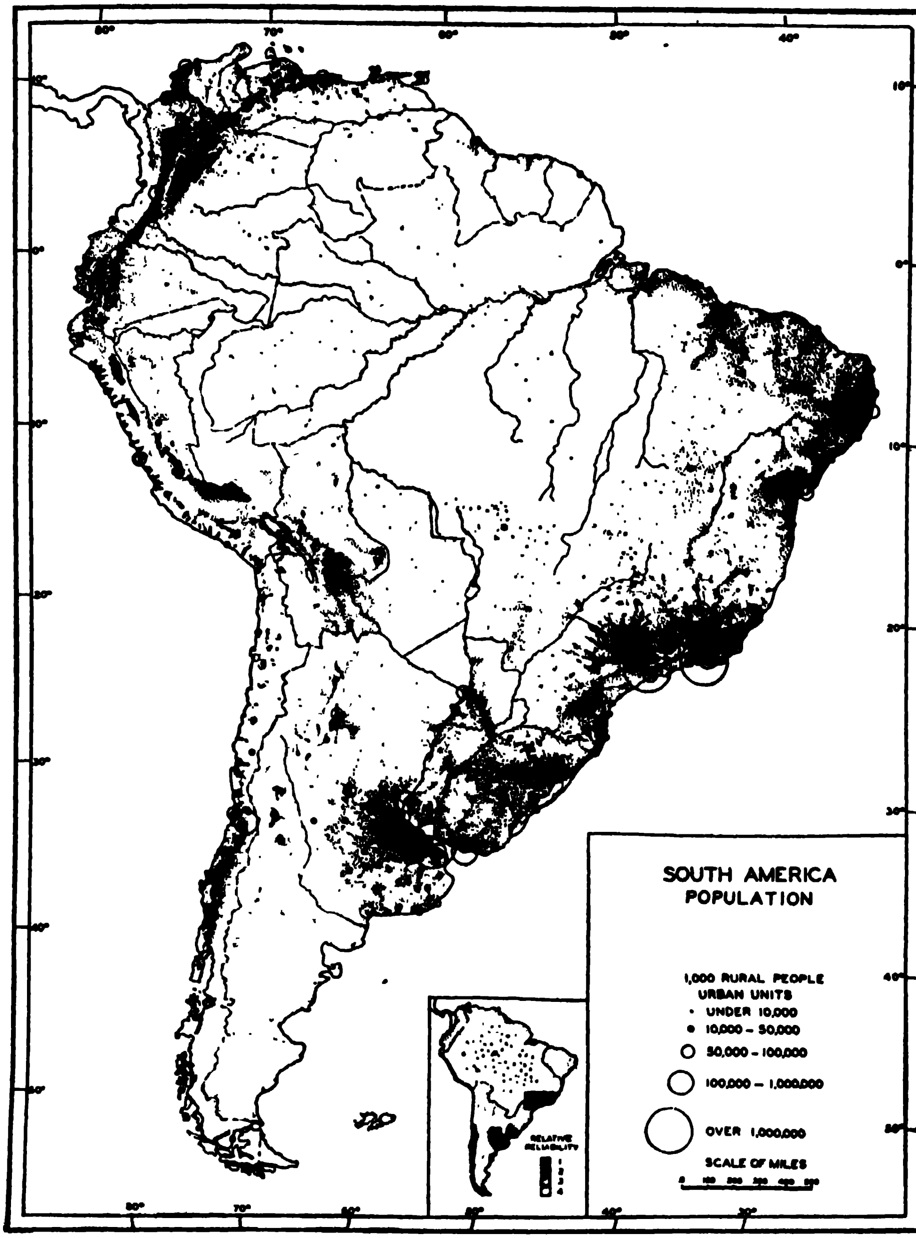


Fig. 386. Population in South America is concentrated in clusters around the perimeter of the continent. (*From Preston James, "Latin America," The Odyssey Press.*)

and southeastern margins of the continent. Most striking of all, however, is the unusual concentration of settlement on the floodplain and delta of the Nile in Egypt, where the population density reaches 1,500 per square mile. The north African Sahara is one of the world's most extensive empty lands, so that the populous Nile oasis stands out by contrast with the surrounding barrenness of the great desert.

2. Density and Movement of Population

744. The Simple Man-land Ratio. How much land there is to how many people is a

fundamental consideration in the life of any society. This relationship of number of men to area of land is called the *man-land ratio*, which, in its simplest form, may be expressed as the number of persons per square mile, square kilometer, or some other unit of area. This is sometimes known as the simple *arithmetic density* of population. In 1946, the earth's population was estimated to be 2,251,000,000, which, expressed in terms of the man-land ratio, was 11 to 12 persons per square mile. But, quite obviously, this figure gives no genuine understanding of real density, for it fails to take into consideration the fact that over 70 per cent of the planet's surface is water, which has no permanent settlements. For the land areas of the earth only, population density is slightly over 44 persons per square mile. This, to be sure, is a more refined and accurate figure than the former, but still it fails to give a very true picture of actual conditions, since human life is by no means evenly distributed over the continents. It appears, then, that the idea of density is almost inextricably tied up with that of distribution. Only where people are dispersed rather widely and evenly over an area is the figure for density alone highly significant (Fig. 387).

Arithmetic Density of Population for Selected Countries about 1938

	People per Square Mile
Belgium	711.3
Netherlands	638.9
United Kingdom	498.8
Japan	482.4
Germany	371.9
Italy	365.6
Switzerland	261.8
India	214.7
France	197.0
United States	42.6
Canada	3.2
Australia	2.3

745. Factors Affecting Population Density. Even in regions where human beings are widely and evenly dispersed, the simple ratio of people to land is not always a satisfactory measure of *real* density. This is because equal areas vary greatly in their capacities or resources for supporting populations. Varieties of climate, surface configuration, soil, vegetation cover, and mineral resources create wide differences in the productivity of land. If, for instance, the ice-covered continent of Antarctica, with an estimated area of 5,000,000 square miles and without permanent settlements, were to receive 100 inhabitants, it probably could be called over-populated, since it has so few resources for supporting human life. On the other hand, the fertile Nile and Yangtze plains can support 100 persons on 1 square mile—five million times the previous density—and still not be considered greatly over-populated (Fig. 387). If, then, in the denominator of the man-land ratio, *productive capacity* is substituted for square miles, a much better estimate of *real* density is obtained. This is known as the general *economic density* of population. The figure for productive capacity of land is not so easily arrived at, however, since the natural equipment of a region is not one but a variety of items. The geographer, trained as he is in the various aspects of natural earth, is equipped to make this contribution relative to the total natural potentialities of regions.

Of somewhat greater significance than arithmetic density of population is the so-called *physiological density*, which substitutes arable

Physiological Density of Population for Selected Countries about 1925
(League of Nations Statistics)

	Inhabitants per Square Mile of Arable Land
Japan	2,532
Netherlands	2,085
Great Britain	2,080
Switzerland	2,007
Belgium	1,664
Brazil	1,661
Norway	1,071
Italy	798
Germany	793
India	533
France	463
Sweden	413
United States	221
Canada	88

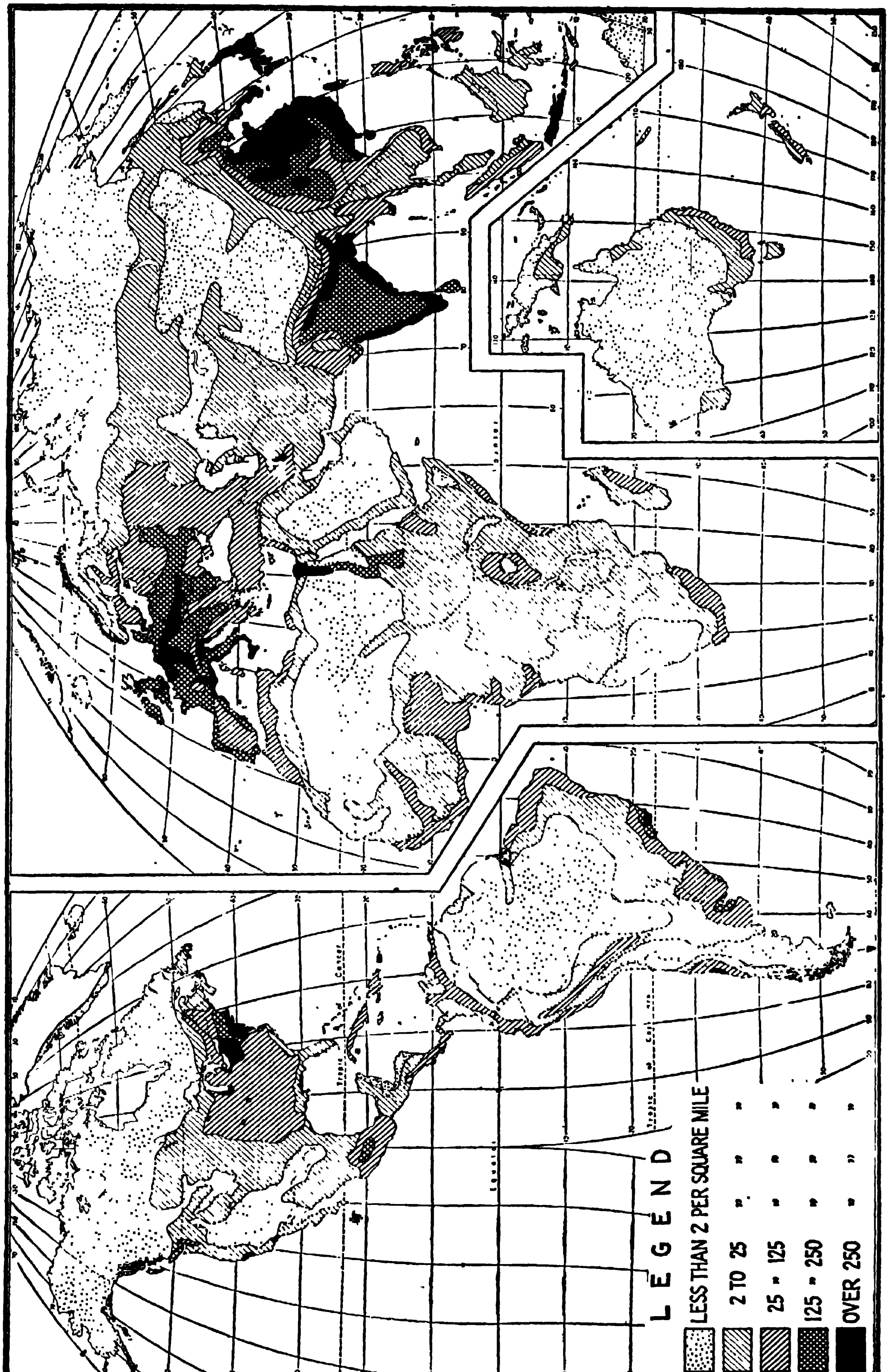


Fig. 387. Density of population.

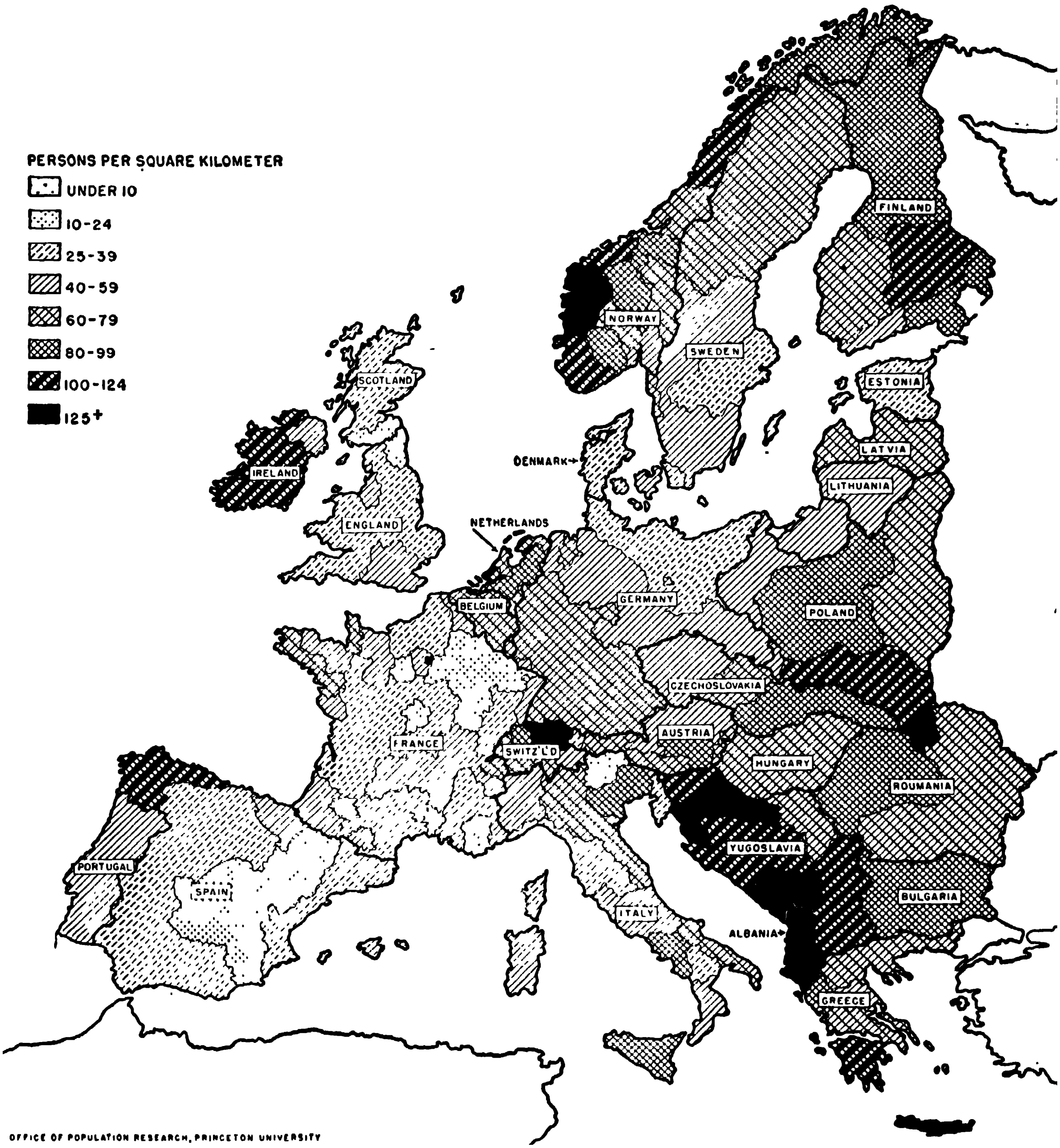


Fig. 388. Density of agricultural population in western and central Europe. (*From Wilbert E. Moore, "Economic Demography of Eastern and Southern Europe." Map prepared by the Office of Population Research, Princeton University.*)

land for total area in the man-land ratio. This is a more refined and accurate index of population density because it omits part of the land which is unproductive. For example in Japan, where less than 16 per cent of the land is under cultivation, the arithmetic density figure is about 500 per square mile, whereas the physiological density in 1940 was over 3,000 per square mile, the highest for any country of the earth. In the table on page 533 are given the physiological population densities for a number of countries. The striking feature of this list, after

noting Japan's position, is the high rank of a number of European countries.

A somewhat different concept is provided by *agricultural density*, which is simply the number of agricultural people per unit of arable land (Fig. 388). Thus Japan, which has a physiological density of 3,000+ per square mile, has an agricultural density of about 1,400, which indicates that slightly less than one-half of the country's inhabitants are agriculturists. In the following table, giving agricultural densities for selected countries, it is conspicuous that there has been a change in the ranks of several nations from what they were in the arithmetic and physiological density tables. It is the countries with relatively dense populations, large percentages of which are engaged in agriculture, that appear at the top of the list. On the other hand, a densely populated but highly urbanized region like Great Britain has a low rating.

Agricultural Density of Population about 1930
(After Reithinger)

	Agricultural Population per Square Mile of Arable Land
Bulgaria	255
Poland	237
Italy	234
Belgium	187
Netherlands	185
Switzerland	172
Hungary	161
Germany	125
France	117
Denmark	99
Great Britain	49

746. The General Economic Population Density in Complex Civilizations. The problem of comparing population density and productive capacity of land becomes further complicated in those regions where men do not live directly from the soil. There is no *simple* way of expressing the potential capacity of areas for supporting population in a complex industrial and commercial civilization. In order to evaluate the general economic density of a country it is necessary to consider, in addition to the agricultural productivity, the various natural resources independent of the soil, such as minerals, timber, fish, and scenery. Additional items to be evaluated are the degree of actual exploitation of these resources and the proportional use of other factors such as capital, quantity and quality of labor, and degree of technical development. For example, the United Kingdom's 50,000,000 people draw only a small part of their economic livelihood directly from the soil of the 94,000 square miles on which they live. Of prime importance in evaluating that country's capacity for supporting human life is its supply of mineral resources, especially coal. With coal as the principal source of industrial power Britain draws raw materials and food from all parts of the world, processes the raw materials in British factories utilizing her accumulated capital and her abundance of high-quality labor, and returns the finished materials again to the far corners of the earth. On the other hand, in simple rural civilizations that are composed of self-sufficient peasant families, the direct relationship between number of people and productive capacity of land is not so difficult to observe. So difficult is it to evaluate the general economic density for the various regions of the world that comparative data are as yet not available.

747. Density Distribution. In the preceding discussion concerned with the distribution of *numbers* of people and the patterns resulting, for the world as a whole and for the individual continents and even a few countries, impressions concerning *relative* densities of different regions have been obtained from the dot maps employed. From such maps, however, numerical density readings are impossible. A more precise and quantitative expression of population density can be observed from Figs. 387, 389, and 390. On the world map (Fig. 387) the most extensive areas of high arithmetic densities, where population exceeds 250 per square mile, are in (*a*) eastern and southeastern Asia, (*b*) western and central Europe, and (*c*) northeastern United States. Within the Orient, which contains the largest areas with high densities, it is eastern China, the Ganges

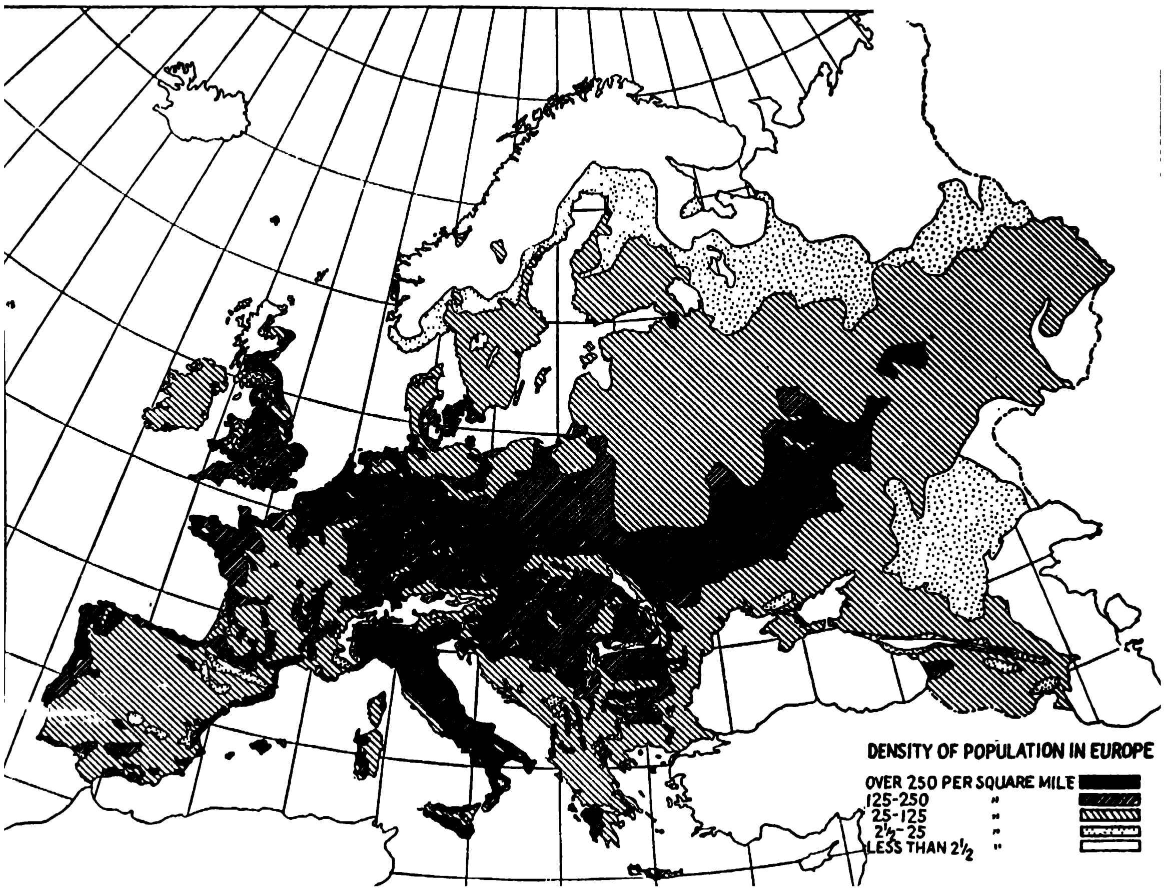


Fig. 389. (*Map by L. Weise. Reproduced by Mark Jefferson and published in the Geographical Review.*)

lowland in northern India, and the coastal lowlands of peninsular India, Japan, Java, and southern and western Korea that show extensive areas with over 250 persons per square mile. In Europe it is the east-west population axis previously described, reaching from southern Britain, Belgium, and Holland on the west to the Ukraine in Soviet Russia on the east, that forms the conspicuous belt of high density. This is the continent's industrial belt as well. A southward projection from the east-west axis follows along the industrialized middle Rhine Valley as far as the Alps. The Po Valley and other smaller plains in Italy, Sicily, and the lowlands of southern France are smaller but still important areas of high population density. In the United States it is the urban industrialized northeastern part, more especially the Atlantic Seaboard states from southern New England to Maryland, and the areas bordering the lower Great Lakes, that have densities exceeding 250 per square mile.

Within the three extensive world regions showing high population densities there are a number of striking contrasts. Chief of these is the fact that in Asia the high densities are those of rural peoples while in Europe and the United States it is to a much larger degree urban population supported by trade and manufacturing. Moreover, within any of the regions shown in solid black on Fig. 387 and, therefore, where *average* densities exceed 250, there are great variations within different localities, with some districts far exceeding the general average. Such variations can be shown only on a much more detailed map. For example, on the

Yangtze lowlands of China the population density is nearly 900 per square mile, on the North China Plain close to 650, and on the plains of Bengal in northeastern India over 600. In several fairly extensive urban areas in Europe and northeastern United States the density figure is several thousand per square mile.

Very low densities of less than two per square mile are characteristic of the subarctic and tundra areas of the Northern Hemisphere continents, most of the deserts, and large parts of the wet tropics in South America. Although it is true that the general lineaments of the world pattern of population densities are directly related to the productive capacities of the lands, the details of the pattern show many exceptions. Not only the natural productivity of regions, but also many social, historical, and political factors are involved in understanding the details of population densities in the various parts of the world.

748. Population Movements. Throughout history the distribution of population densities has changed from period to period as a result of (*a*) differential rates of natural increase in the various earth regions as determined by fertility and mortality rates and (*b*) the migration of peoples. Some of the most important events in world history are associated with large-scale movements of human beings in the process of abandoning their former homeland for some more or less permanent new domicile. Such a migration occurred when the Aryan ancestors of the present Hindus left the desert and oasis environment of Turkestan, crossed the mountain barriers of northwestern India, and occupied the better watered lands of the plains of Hindustan. The populating of Anglo-America by floods of immigrants from Europe is a more recent example of a migration of gigantic proportions which changed the course of world history. Some migrations have been of long duration extending over centuries; others were much more rapid.

Wherever large-scale movements of people occur, important modifications result both in the emigrating group and in the original inhabitants of the land being occupied. Thus the

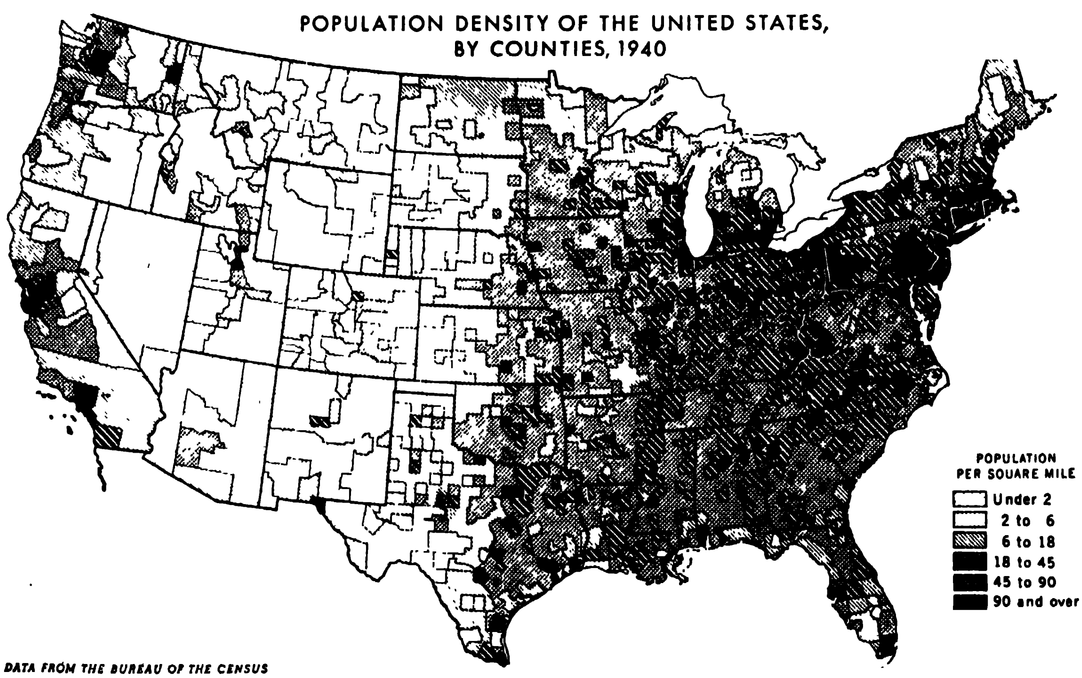


Fig. 390. (*U.S. Department of Agriculture.*)

European invasion of North America resulted in a near extermination of the aboriginal peoples of that region, and there was very little mingling of the cultures of the resident and immigrant groups. In Latin America, on the other hand, where the Indian civilization was more advanced than it was farther north, there resulted a much greater fusion of native and European cultures and the very large mestizo element in the present population is the result.

749. *The Causes of Large-scale Migrations are Twofold.* There are those which are the result of *physical* causes, while others have been of *socio-economic* origin. Among the physical causes of migration may be mentioned such items as climatic changes or great cataclysms such as floods, volcanic eruptions, or famine. Such causes were probably more important in motivating primitive migrations than they are in those in more advanced societies. Some scholars are of the opinion that the outpourings of the nomadic peoples of dry inner Asia on several occasions during the Middle Ages, and their invasion of the more humid lands of China to the east and of Europe to the west, were associated with long periods of serious drought in the homeland of the invaders.

Probably of greater importance in causing large-scale movements of peoples are the socio-economic causes. Among these are (*a*) defeat in war by invading migrants, (*b*) economic hard ship in the homeland, (*c*) greater economic opportunities elsewhere, and (*d*) religious persecution. The large emigration from Ireland during the nineteenth century had its origin, in part at least, in the severe economic distress in that island. Religious persecution had much to do with the flight of the Huguenots from France and of Jews from Hitler Germany. The unusual economic opportunities offered in the new lands in the Americas, Australia, New Zealand, and South Africa were the magnet that drew millions of immigrants to those shores. Contrasts in *economic* population densities in different parts of the world cause peoples to move from regions of high economic density to those of low. As winds and rivers flow down gradient, so also is there a tendency for peoples to do likewise, although to be sure the process is by no means so simple in the case of human beings as it is with inanimate fluids such as air and water. Migration is always dependent upon the establishment of means of communication between the regions having contrasting economic densities of population.

750. *Intercontinental Migrations.* By far the greatest of the intercontinental migrations was that which occurred during the seventeenth to the nineteenth centuries as European peoples spread to the new lands of the Americas and to Australia, New Zealand, and South Africa. The flood tide of this movement occurred in the nineteenth century when between the years 1846 and 1932 more than 50 million emigrated from Europe, thereby not only populating the new lands in which they settled, but carrying to them as well the elements of European culture. In the new soil of the Americas, Australia, and South Africa the seeds of European civilization produced sturdy plants which, while they strongly resembled the parent stock, bore earmarks of the new environment as well.

The first European emigration, that of the seventeenth and eighteenth centuries, was associated with the colonial policies of the several European countries, most of whom were interested in those regions capable of being exploited for their precious minerals or stones or for such rare products as spices. Great Britain was the only European power at that time whose demographic and economic conditions permitted the sending abroad of large numbers of immigrants qualified to establish productive settlements. It was that country, therefore, which eventually acquired political control of most of the new lands lying within the middle latitudes. The total number of emigrants leaving the British Isles for the New World in the seventeenth century was about 500,000 and in the eighteenth century, 1,500,000. The total German intercontinental migration up until the beginning of the nineteenth century is estimated to have been about 200,000.

The nineteenth century saw a decline in European emigration associated with government-sponsored colonization and a gigantic

expansion in free emigration. By the middle of the century the annual departures from the British Isles reached 300,000; in 1854, 240,000 Germans left the homeland, of whom 215,000 went to the United States. Between 1840 and 1880, a total of 9,500,000 immigrants, 90 per cent of them from Europe, entered the United States. In the decade following the American Civil War the annual emigration from Europe averaged around 350,000 to 375,000.

751. *Intracontinental and Intranational Migrations.* Of the above types, the one of most outstanding importance to American students has been the westward movement of population in the United States contemporaneous with advance of the frontier. The West was settled from the East. It was this migration westward of population and the frontier that brought about the agricultural development of the country. Up until about the time of the Revolutionary War population was concentrated in the Atlantic Seaboard colonies, and to the east of the Appalachian barrier. By 1860 the westward migration was so far advanced that states as far west as Ohio, Kentucky, and Tennessee were losing more people by migration than they were gaining. The great westward movement of population continued until 1920, after which year the great flow into California was its only manifestation.

In the period just preceding the Second World War some of the largest streams of population movement existed in eastern Asia. From North China there went annually over 1 million people into the frontier lands of northern Manchuria. Between these two regions the population gradient is very steep. Another stream of Chinese emigrants, chiefly from South China, moved toward the less well populated regions of Malaya, Siam, French Indo-China, and the Netherlands Indies, omitting Java. From the densely populated delta lands of Bengal there was an important trek toward the less well occupied Assam Valley.

Another type of intranational migration has been that associated with a movement from rural to urban areas, a type which accompanies industrialization and urbanization. In the United States agricultural settlement had extended over the entire country by 1930, for during the decade 1920–1930 almost all the agricultural states were giving up population to the industrial areas. The increasing mechanization of agriculture, especially after 1920, which decreased the amount of farm labor necessary, and the great industrial expansion in the northeastern part of the country, has tended somewhat to reverse the earlier westward flow of population in the United States (Fig. 391). As early as 1890 New Jersey, Massachusetts, and Rhode Island were gaining population by migration from other states. It was not until the decade 1920–1930 that Illinois and Indiana had a net gain of immigrant population because of enlarged industrial activity. During the decade 1920–1930 the rate of increase in urban population for the entire country was more than six times the rural rate, indicating a very large rural-urban migration. The result was a net migration from farms to cities of more than 8 million people, 75 per cent of them 25 years of age or younger. In the following decade, however, this trend toward the cities halted very sharply, for the rate of increase was almost identical for rural and urban groups.

Similar rural-urban migrations have occurred in other rapidly industrializing countries. In Japan during the two decades 1920-1940 urban population increased from 32 to 50 per cent of the nation's total, while rural population declined in the same proportion. During this same period, population outside communities of 30,000 or more remained almost static, so that the total national increase of over 17 million must have been absorbed by the cities.

Some of the most recent and tragic of human migrations have been those associated with the Second World War. It is estimated that some 20 million people were uprooted from their homes by the war and forced to migrate. More than half of these were people from Allied countries who were recruited or forced to work in Germany. Probably more than 2½ million displaced Germans followed the German armies into occupied territories. About 2 million alien fugitives, chiefly Poles, migrated to the Soviet

URBAN AND RURAL POPULATION OF THE UNITED STATES, 1790-1940

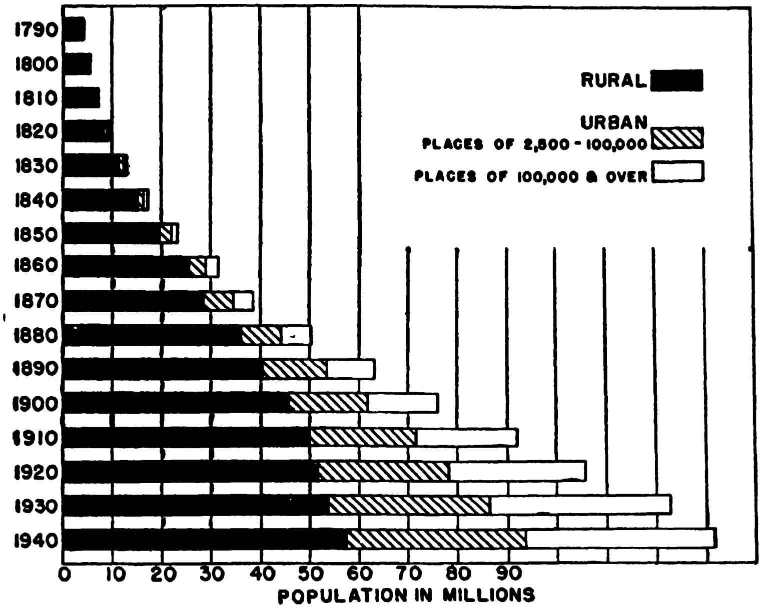


Fig. 391. (*Office of Population Research, Princeton University.*)

Union. Over 1 million Jews left Europe just prior to and during the war.

752. *Daily and seasonal migrations* of labor comprise still another phase of population movement. Between 1907 and 1913, Argentina annually recruited about 60,000 laborers from Italy and Spain to work in her harvest fields. Following the harvest season they returned again to their homelands. A few decades ago, before laborsaving machinery was so common on American farms, 250,000 transient laborers were required for the grain harvest. They began their work at the southern margins of the winter grain region in early summer and moved northward with the harvest season. Before the First World War 5 to 7 million Russians made periodic journeys to work on farms and in factories. In California alone some 150,000 transient laborers are employed in fruit picking.

Large-scale daily migrations of people are characteristic chiefly of large cities. The downtown section of any large city is an area of extraordinarily high population densities by day but, on the other hand, is relatively depopulated at night. This inward surge of people toward the heart of a metropolis in the morning, and toward the peripheral and suburban residential areas in late afternoon, is a recognized feature of almost all urban areas. Such large-scale commuting is made possible only by efficient communication systems.

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CHAPTER 29: *Settlements and Their Houses*

753. By the term *settlement type*, as applied to any region, is meant the characteristic colonization or occupance unit. These units vary in size and complexity from the simple isolated one-family farmstead of the Iowa prairies on one hand, to the great urban metropolis such as New York or Chicago on the other. In either case, however, the farmstead or the metropolis, the settlement unit represents an organized colony of human beings together with the buildings in which they live or that they otherwise use and the paths and streets over which they travel.

It is unfortunately true that there does not exist at the present time sufficient reliable information to permit the writing of a satisfactory discussion of house and settlement types in terms of their world distributions and the principles involved in these distributions. Important as these geographic elements are, therefore, the following brief analysis of them is obliged to be more in the nature of comments on the characteristics of houses and settlements in a few particular regions. Any world classification into types, with accompanying maps showing distribution of these types, like those provided in this book for some other geographic elements such as climate, native vegetation, soils, and agriculture, is still impossible.

Houses

754. The House a Fundamental Geographic Element. The two most fundamental requirements of human beings are food and shelter, and much of the imprint left by peoples upon areas that they occupy results from activities associated with those two requirements. Since human beings cannot escape sleep, they are compelled to seek shelter, both from enemies and from the elements. This sleep shelter, no matter how crude, is a critical focus in the life of any individual, since he is forced to return to it for periodic protection. The house, then, becomes a universal feature of regions permanently occupied by human beings and is one of the most fundamental elements of cultural geography.

As used here, the title "house" is meant to include not only the dwelling house, ranging from the humblest native tropical huts to the most elaborate city mansions, but all other human structures as well, where people congregate or where their goods are stored, such as schools, factories, warehouses, churches, and stores. In primitive societies the dwelling unit greatly predominates, but in more advanced civilizations there is a much wider variety of buildings, such as storage structures for crops and food, shelters for domestic animals and machines, and numerous other types having industrial, commercial, transportational, pleasure, and religious functions.

755. Distinguishing Features of Houses. In describing and classifying houses, one of the first problems that arises is the necessity of making a decision relative to what characteristics of houses are geographically significant, setting apart the buildings of one region from those of another. Certainly among the more important items employed in differentiating houses is the one of *building materials*—earth, stone, brick, steel, wood, etc. Likewise important are such items as *size*, *shape* or *form*, *colors*, *spacing*, and *function*. Sometimes it is one feature of a region's buildings that gives distinctiveness

Fig. 392. Japanese rural houses. (*Photograph by John Embree.*)

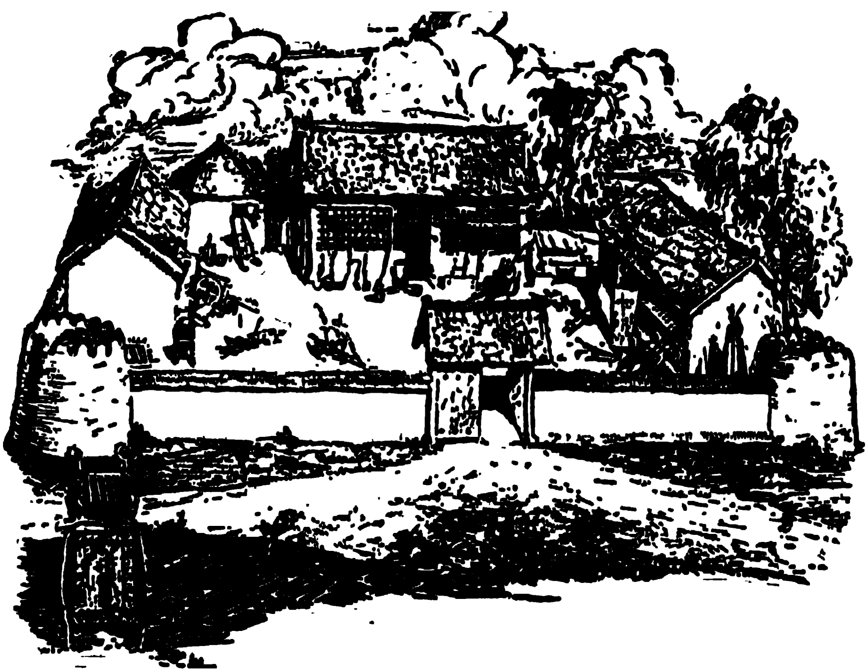


Fig. 393. A representative rural house in northern China.

to the group; sometimes it is another. In Norway, for instance, the bright colors of the houses—blues, reds, and whites—are particularly striking, especially so in that region where dark weather predominates. In northern Russia the carved gables, gaily painted, are a distinctive feature. The white stucco walls and red-tile roofs of the newer houses and the wooden bungalows representing an earlier period of building are both typical of southern California. Japan's houses are distinctive by reason of their close spacing, flimsy frame construction, and heavy thatch or gray-tile roofs (Fig. 392). The Chinese house, of frame construction with walls of adobe or brick, possesses individuality, in part, at least, because of its form, being characteristically built around a court[1] (Fig. 393). In certain wealthier sections of our larger cities it is often the size and magnificence of the dwelling units that are distinctive, as is the case with those along Park Avenue and Riverside Drive in New York City and with the estates along the Hudson north of the same city (Fig. 394). Obviously it is possible to have a great variety of house types resulting from different combinations of materials, size, color, shape, and functions.

756. House Materials as a Basis for Classification. One of the simplest and most useful classifications of houses may be based upon the *kind of materials* used in construction, although of course such a classification would be far from complete and inclusive. In primitive societies there is a strong tendency to use those materials readily at hand furnished by the natural earth, provided, of course, they are suited to the prevailing climatic conditions. Noteworthy examples of this tendency are the snow huts, or *igloos*, of the American Eskimo; the *tents* and *yurts*, made of felted hair and wool from their flocks and herds, used by the nomadic peoples of dry interior and western Asia; the *thatched frame-and-wattle huts* of peoples in the tropical rainforest; or the *adobe* dwellings of village peoples in dry lands.

[1] J. E. Spencer. The Houses of the Chinese. *Geog. Rev.*, Vol. 37, No. 2, pp. 254–273, 1947.

Fig. 394. An apartment hotel on the shores of Lake Mendota in Madison, Wisconsin.

757. House Belts in Russia. Brunhes, in his book "Human Geography," points out that in traveling from north to south in European Russia, where a succession of natural zones is crossed, one is struck by the regular succession of dwelling types. Thus in the tundra, where trees and cultivated crops are absent and where human life is nomadic, there are no fixed habitations, the summer dwellings of the natives being light tents made of reindeer skins, while in winter covered earthen pits serve as houses. To the south of the tundra is the wide belt of forest, coniferous and deciduous, and within that natural region the wooden house is the prevailing type. It might be added that the wooden dwelling is common to many other forested regions such as Sweden, Čechy (Bohemia), the Alps, eastern United States, and Japan. In its simplest form it is constructed of the straight trunks of trees, notched at the corners and laid one on top of the other. The log house of the American pioneer often was of this type (Fig. 395). In more advanced societies the logs

Fig. 395. A log house in Kentucky.

are first sawed into boards, and these are used for sheathing a wooden skeleton or framework. For roofing material, shingles, bark, or thatch are common. Still farther south in Russia, where forest gives way to prairie, the wooden house becomes much less frequent, and sod and adobe dwellings roofed with thatch or pieces of turf are the prevailing type. Simple sod structures likewise housed the early settlers on the American prairies and were common to the Argentine Pampa as well (Fig. 396). Beyond the prairie belt in Russia, in Crimea and the Caucasus, where stony steppe prevails, houses of stone tend to replace the sod hut.

758. *Complexity of House Materials in Complex Civilizations.* In more advanced and complex societies, where transportation is better developed, there is nowhere near the same dependence upon local building materials as there is in more primitive and frontier civilizations. As a consequence, there is likely to be a greater variety of house types, even in the rural parts of regions having well-developed transportation systems. Buildings on an American farmstead, although predominantly of wood, are not infrequently constructed of brick or stone. It is in the city, however, where the danger of fire is greater, and where larger buildings are more common, requiring stronger and more durable materials, that the greatest variety of house types prevails. In the downtown business sections there predominate closely spaced, relatively tall buildings of brick, stone, and cement supported by a steel framework. Typical of larger American cities is the many-storied skyscraper. Throughout the residential districts wooden houses still are common, although those of brick and stone are very numerous (Figs. 397 and 398). In European cities the wooden house occurs less frequently. In Japan, on the other hand, it is the prevailing type. One European writer has likened the Japanese dwelling to a wooden cage lightly placed upon the ground. It is never painted,

Fig. 396. A sod house on the Argentine Pampa. (*Photograph by H. G. Olds.*)

Fig. 397. Early American house of local stone at Prairie du Chien, Wisconsin.

Fig. 398. Good substantial residences of brick and frame construction in an American town.

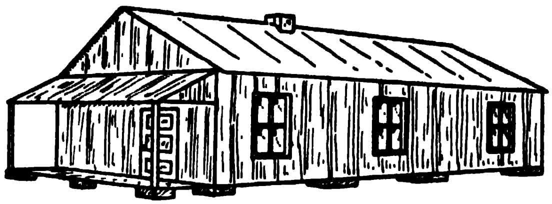
and consequently the color is that of weathered wood.

759. *Durability of Materials.* In those parts of the world where wood is the dominant construction material in cities, owing to the destructiveness of fires, very old buildings are rare. It is said that there are few really ancient buildings in all of Japan. In Europe, on the other hand, numerous stone and brick buildings have stood for centuries, and some for more than a millennium, preserving for this modern age some of the culture of ancient and medieval man. In Greece, Rome, and Egypt the evidences of ancient civilizations still persist in the form of magnificent stone ruins. "When the vigorous life which throbbed in such structures of stone ebbs or dies out completely, the ruins still enable one to imagine what they must have been originally." (P. Vidal de la Blache.) In Assyria and Chaldea on the other hand, where temples and palaces were built chiefly of less durable clay, their sites are now only mounds of earth.

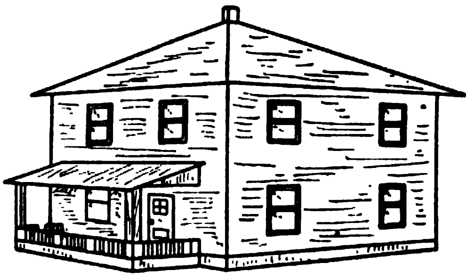
760. *House Form and Shape.* Other than materials, the ground plan and shape of houses are basic elements differentiating the residences of one region from those of another. Previously mentioned is the distinctive plan of the Chinese house built around a court. In the United States, as one travels the length and breadth of the country, a little pointed observation reveals basic regional contrasts in house form. By means of a 1,650-mile car traverse from Madison, Wis., to Beaumont in southeastern Texas, in which 3,464 rural houses were observed, 16 fundamentally different types of houses were distinguished.[1] Most numerous type and common to both the northern and southern sections of the country was the bungalow. In the North other than the bungalow, two-story **L**, **T**, and ▬ houses were the most common types. Smaller one-story rectangular cabins and cottages were characteristic of the South (Fig. 399). House materials were of practically no value in differentiating the structures, since 94 per cent of the total were of wood and 91 per cent of sawed lumber. Unpainted houses, chiefly in the South, comprised nearly 40 per cent of the total number, and 38 per cent were painted white.

To even a layman with any appreciation of architectural qualities the contrast between many of the fine old farmhouses of New England, New York, and Pennsylvania on the one hand, and the unlovely rural houses of the Middle West, built at a later period, is striking.

[1] Robert Finley and E. M. Scott. A Great Lakes-to-Gulf Profile of Dispersed Dwelling Types. *Geog. Rev.*, Vol. 30, pp. 214–219, July, 1940. See also Fred Kniffen, Survey of Rural House Types in Louisiana. *Ann. Assoc. Amer. Geographers*, Vol. 26, pp. 179–193, 1936.



(a)



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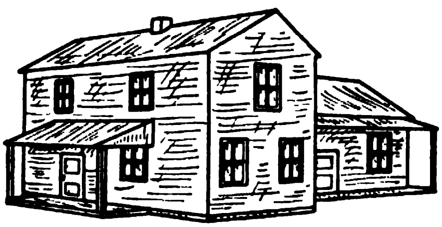

(c)

Fig. 399. (a) A rural house type characteristic of the American South. (b) and (c) Rural house types common in the North. (*Courtesy of Robert Finley and E. M. Scott.*)

One of the most attractive features of travel in rural New York and New England is the number of fine old homes in the villages and on the farms. Their excellent proportions, simple lines, and straightforward sturdy appearance brand them as being architecturally good. By contrast, farm and village houses throughout the Middle West are notoriously lacking in these same qualities. Seemingly the farther back from the Atlantic Seaboard one travels the fewer farmhouses of architectural merit there are. In New York they are numerous, in Michigan there are many fewer, and in Wisconsin they are a rarity. What is probably still more strange is that in New England, where they had good models in the Colonial farmhouses right at hand, their modern creations show a definite deterioration in quality. It is not clear why the offspring of the Colonial farmer-carpenters, whether at home or in the Middle West, seemed to lose their eye for good house form.

Settlements

761. Two Primary Types of Settlements. Although geographers are concerned with the representative house types in different parts of the world, they are even more interested in the characteristic groupings of houses, together with their inhabitants and creators, into occupance units or settlements. Based upon form and function, two great subdivisions of settlements are here recognized: (*a*) the *isolated*, or *dispersed*, *type* in which the single residence unit is the distinctive nucleus, as it is, for instance, on an American farmstead; and (*b*) the *agglomerated type* in which there is a collection of several or many residences, together with other types of buildings (Fig. 400). Agglomerated settlements are designated by various names according to their size and the complexity of their functions. *i.e.*, hamlets, villages, towns, and cities. In all of them, however, the two most conspicuous features are always the *house* and the *street.*

DISPERSED SETTLEMENTS

762. Character and Advantages of Dispersed Settlements. For the most part, dispersed settlement, where the one-family residence stands isolated and apart from others, is characteristic of agricultural areas. In some parts of the world hunters, trappers, fishers, and miners may live in open-country dwellings, and, in the United States at least, there is a sprinkling of nonfarm residences scattered throughout the rural areas. Nevertheless, for the world as a whole, the farmer is by far the most numerous open-country dweller. To such a degree is this true that the dispersed settlement unit is often taken to be synonymous with the farmstead.

The outstanding characteristic of dispersed settlement is the minute size of the settlement unit, *viz.*, the family, and the isolation and

privacy in which it exists. Such isolated living tends to separate men psychologically as well as economically. Admittedly there are both advantages and disadvantages to this system of open-country living, the advantages being chiefly economic and the disadvantages social. Economically the isolated farmstead, located on a compact and unified farm, has the advantage of keeping the farm family at its place of work and near the fields and animals that it cultivates and rears. There is not required the time-consuming movement between home and fields that is necessary when the farmer is a village dweller, with his scattered fields located at some distance from the residence. Freed from the restrictions associated with living in a village with other farmers and working the surrounding fields along lines developed for the village as a whole, the isolated farmer is much more independent as far as his methods of farm management are concerned. He is less obliged to conform to any pattern as set by others, and therefore the energetic, resourceful farmer is able to forge ahead of his less ambitious neighbors. Freer reign is given to individual initiative and enterprise so that there is less of a dead level in the farming population, and stagnation is less likely.

Many would argue that the offsetting social disadvantages of open-country dwelling more than compensate for these economic advantages. They consider that whatever economic progress has been attained by the change from the farm village to the system of dispersed settlements has been at a fearful cost in terms of social values. The sense of neighborly interdependence and the solidarity and strength fostered by the village communal agriculture are greatly weak-

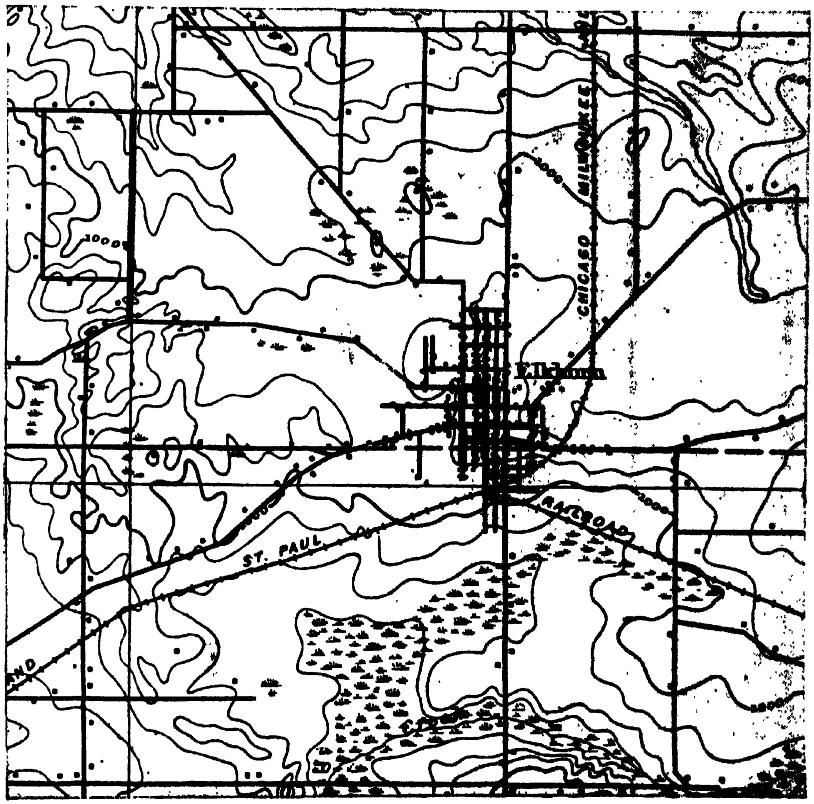

Fig. 400. Illustrating clustered and dispersed settlements. A market town in Wisconsin surrounded by isolated farmsteads. The latter are indicated by tiny black squares. (*Elkhorn sheet.*)

ened when farm families live isolated and alone. The close, warm, communal life of the farm village, the feeling of being an integral part of the life of many men, is lacking. Moreover, the only neighbors of an American farmer are other farmers and they are at some distance, and this prevalence of men of his own vocation tends to weaken his sense of economic and social interdependence. The division of labor between different classes in a farm village serves as a constant reminder to its residents of neighborhood interdependence. An additional social handicap in open-country living is that the farmer labors much of the time alone except perhaps for the company of his team of horses or a dog. It is a lonesome labor unrelieved during long hours by association with his fellow men. Much of the farm work in rural villages, on the other hand, is done in groups or gangs, and this fellowship in labor introduces an element of the play spirit into even the most arduous work and relieves it of its boring qualities. This lightening of the load when men work together is experienced on an American farm chiefly on such occasions as silo filling and at threshing time.

763. Origin and Distribution. The historical record is not entirely clear as to the origin of dispersed settlement, but evidence seems to indicate that the rural village was by far the most common type of agricultural settlement prior to the enclosure of English open fields. Certainly before that event the prevailing custom was for farmers to live in rural villages. The movement for enclosures and the associated disintegration of the English farm village falls into two periods, 1485–1560 and 1760–1820. It grew out of a need for a more efficient and economical system of cultivation than was possible under the village type of agricultural settlement with its characteristic pattern of scattered fields with much land held in common. These same needs have caused the dispersed type of settlement to spread to other parts of the world as well.

At the present time the open-country type of rural settlement, with the individual farmstead set down in the midst of its fields, is almost universally characteristic of rural United States and of the agricultural sections of Canada. In the United States almost the only clear-cut example of the agglomerated farm-village type of rural settlement is to be found in the Mormon regions of Utah.

Outside Anglo-America dispersed rural settlement appears to be strongly characteristic of Australia and New Zealand, of the Scandinavian countries, the small Baltic States, and the British Isles in Europe, and of Argentina and Uruguay in South America. Smaller regions of dispersion or regions where that form of rural settlement is less dominant are the highland regions of Mexico, Costa Rica, western Panama, the Orinoco Lowlands in Venezuela and Colombia, the Lake Maracaibo Lowland in Venezuela, southern Portugal, western France, the highland areas of central Europe, northern Japan, northern Manchuria, Szechwan province in China, and scattered areas in South Africa and in the East African Highlands.

764. Reasons for Dispersed Settlement. Numerous attempts have been made to find a logical explanation for the world distribution pattern of dispersed settlements described in the preceding paragraph, but without a great deal of success. The reasons for this type of settlement appear to be different in different regions. In more recently settled areas such as the United States, Canada, Australia, and Argentina, the abundance of cheap land, resulting in large farms, has probably been the principal factor fostering separate farmsteads. Where the unit of cultivation is several score, or even several hundred acres, all in one single holding, village type of settlement would have resulted in much loss of time and energy going back and forth between residence and fields. Nevertheless, the Russian colonists in the spring wheat belt of Siberia characteristically live in villages, this tendency to live together even in a region of new and abundant land perhaps reflecting the dominance of agglomerated settlement in European Russia.

765. ***Natural Factors.*** There appears in certain parts of the world to be some relationship between natural factors, particularly surface

configuration, and settlement type. A number of European writers have observed that dispersion appears to increase in direct proportion to the ruggedness of the land surface. In other words, isolated farmsteads are more characteristic of hilly land, and compact rural villages reach their maximum development on plains. In Japan this is strikingly true. The relationship has been noted likewise for Switzerland, Germany, southwestern Poland, Austria, Hungary, and Slovakia. In southern Europe, the Dinaric Alps and the Carpathians stand out as marked centers of open-country dwelling. The explanation, in part, may lie in the physical character of such locations, the whole aspect of which leads to a diffusion of resources—arable land, water, and natural sites with pleasant exposures. Vidal de la Blache writes: "The scattered manner of grouping suits localities where, as a result of the dissection of relief, soil, and hydrography, the arable land is itself divided up. The clustered village is indigenous, on the other hand, in districts where the arable area is continuous, admitting of uniform and extensive exploitation."[1] In regions of dissection and abundant slope, the scattered fragments of cultivable land are often too small to support more than a few isolated farmsteads. The inhabitants are compelled to utilize other resources, such as pastures and woodland, which in turn require larger landholdings. It should be pointed out, however, that the foregoing generalization concerning type of rural settlement and associated relief does not have universal application, for there are numerous hilly regions of the world where the farm village is characteristic. In regions where both types of rural settlement are common, however, there is often a tendency for the isolated farmstead to be more characteristic of the hilly portions.

Certain other natural factors are believed to act in a manner similar to relief in restricting the amount of contiguous arable land and thereby favoring dispersed settlement. Scarcity of water, marshes, forests, stony moraines, and poor soils are some of these adverse elements. In Poland, for example, areas of poor soil, marshes, and dunes are considered to be sites of ancient open-country living. In Shropshire, England, villages prevail except in the heavily wooded country without fertile alluvium. In Germany and Finland there appears to be some correlation between areas of poor soil and dispersion. Dispersion is said to be possible in Flanders because of the abundant ground water, whereas in parts of Russia and southern Belgium the restricted number of places where water is available handicaps widespread open-country living.

766. *Cultural Factors.* Type of economy and historical changes have also been instrumental in affecting the present pattern of world settlement types. In Europe dispersed dwellings are common in regions where pastoralism and transhumance are important. The moorlands of Wales and Yorkshire, used chiefly for grazing, are islands of dispersions within larger regions of village dominance. In Switzerland, Austria, and Norway the highlands are seasonally occupied by herders who live in dispersed chalets, Almhütte, or saeter huts. The pastoral Lapps appear to live in dispersed fashion except in winter, when they gather in hamlets or take lodging with some peasant.

During those periods when farmers had need of defense against hostile neighbors, there was good reason for their congregating in villages, where better protection of life and property could be made. As defense needs became less significant, open-country isolated living became more prevalent. The decline in feudalism with the associated freeing of the serfs and the change from communal to private land tenure likewise favored the decline of the farm village and an associated increase in the number of separate farmsteads. The Industrial Revolution, improved transportation, and the rise of commercial agriculture had much the same effects. Recent agrarian movements in Poland, Czechoslovakia, Hungary, and other countries, where estates have been dissolved and the land divided among the peasants, has led to further dispersion. The rapid increase in population in

[1] P. Vidal de la Blache. "Principles of Human Geography." P. 316. Henry Holt and Company, Inc., New York, 1926.

Europe since the Industrial Revolution has been a factor leading to colonization of available agricultural land by single families. Thus on the Danube Plains, which has been one of Europe's most exclusive regions of farm villages, there is an increased number of isolated farmsteads on the Pustza lands between the older settlements. At first this took the form of summer occupance of isolated dwellings in the midst of the fields, but with a return to the villages in winter. Recently there has been a growing tendency to continue residence away from the villages in winter as well as in summer, so that genuine dispersion is developing.

In summary, it may be repeated that no very valid generalizations having world-wide significance can be made explaining the present distribution of open-country dwelling over the earth. Most of the explanations given in the preceding paragraphs have chiefly local significance. At the present time the drift appears to be away from the farm-village type of settlement and toward open-country living. Some of the reasons for this trend have been touched upon in preceding paragraphs. With this growth of open-country living there are bound to arise serious social problems.

767. *American Farmsteads.* The farmstead is the center of operations on an American farm. It contains the operator's residence; barns and sheds for the shelter of animals, the storage of feeds and the protection of machinery and tools; together with adjoining feeding pens and yards, a home garden, and possibly an orchard. Usually it varies in size from a fraction of an acre to a few acres in extent. But although it is the heart of the farm, the farmstead is its unproductive part, in so far as primary goods are concerned. The fields are the sources of the raw materials from which salable or consumable agricultural products are made. It is at the farmstead that these raw materials from the fields are collected, processed, stored or fed, and made ready for sale. To a geographer farmsteads are one element of a region's settlement fabric. Not only their spacing and distribution

Fig. 401. Aerial view of a farmstead in Illinois. (*United Photo Shop.*)

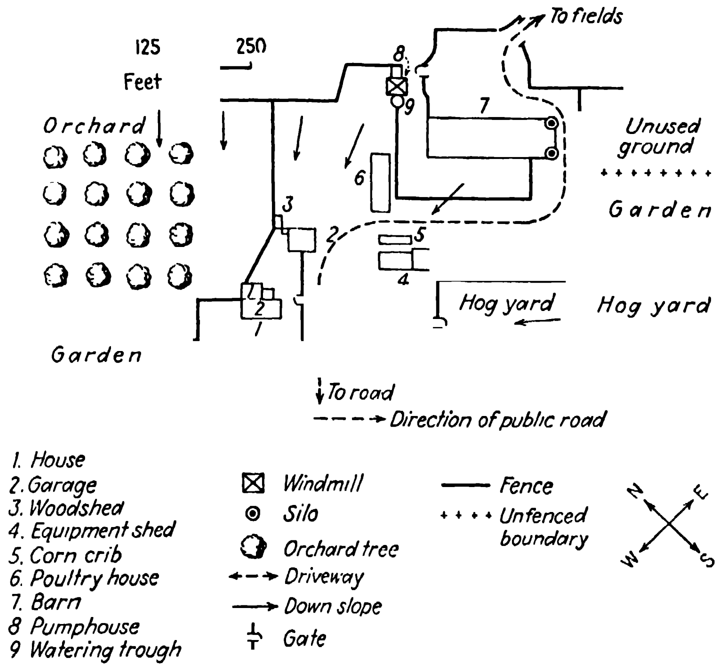

Fig. 402. Plat of a farmstead on a Wisconsin dairy farm.

as units, which in a real sense is a measure of farm population, but also their areas, dimensions, locations, number of buildings, and the sizes, functions, and arrangement of their buildings, are essential ingredients of a region's settlement geography (Figs. 401 and 402).

In a recent study[1] made of approximately 1,700 farmsteads distributed over seven agricultural regions of the United States, an attempt was made to discover some of the salient contrasts in farmstead characteristics in widely separated areas of agricultural specialization. Of the farmsteads studied, those of the dairy region of western Wisconsin, had, on the average, the highest standards, with those of the New York–New England dairy region and of the Corn Belt ranking next in order. Least pretentious and attractive were those of the Cotton Belt and of the range livestock region. The western Wisconsin farmstead is of moderate size, averaging about two acres in extent. The number of farm buildings characteristically varies between 6 and 12. In none of the other regions analyzed is the number of farm buildings so numerous. Substantial farm homes that are well painted and of good size are characteristic. Only the eastern dairy region has larger farmhouses. In the items of barn size and the proportion of barns painted the western Wisconsin dairy region ranks first. Thirty-seven per cent of the barns cover 12,000 to 20,000 square feet of area; 63 per cent cover over 20,000 square feet; 14 per cent of the Wisconsin farmsteads have more than one barn. In the percentage of farmsteads having one or more hog houses, machine sheds, corn cribs, and silos this same region exceeds all the others, and only the cash grain region outranks it in the ratio of granaries. Sixty-five per cent have one or more corn cribs; 61 per cent have at least one silo; 8.5 per cent have two silos; 40 per cent have windmills.

By contrast with the relatively pretentious farmsteads of western Wisconsin, the Corn Belt, and the New York–New England dairy region, those of the Cotton Belt are distinctly less pros-

[1] Glenn T. Trewartha. The Regional Characteristics of American Farmsteads. *Ann. Assoc. Amer. Geographers*, Vol. 38, No. 3, pp. 169–225.

perous looking. They are smaller in area and have few farm buildings, and the latter are of small size. Eighty-seven per cent of the farm homes studied are one-story structures, and nearly 70 per cent have six rooms or fewer. Ninety per cent of the Cotton Belt houses lack basements, barns are relatively small, and both houses and barns are conspicuous by their lack of paint. Windmills and silos are rare, while farm buildings such as garages, hog houses, and machine sheds are relatively fewer than in the other regions studied. On the other hand smokehouses are more numerous in the cotton region than elsewhere. Farmsteads in the cash grain region are distinctive by reason of their large size, the relatively large proportion of windmills and granaries, and the high percentage that are set back from a public highway. In the Puget Sound–Willamette Valley, farmsteads are entirely lacking corn cribs but, on the other hand, they rank highest in the proportion of home orchards. It becomes clear from the preceding analysis that American farmsteads are regionally distinctive.

It needs to be emphasized that the farmstead is not, however, just an agglomeration of buildings and yards; it is, rather, the focus or nucleus of a "culture structure with functional significance," a structure composed of human beings, the buildings that they occupy and use, the fields that they cultivate, and the livestock that they raise. Unlike the medieval manor, the American farmstead is not a self-sufficient unit, for many of the farm family's needs are supplied from the shops of nearby market towns and paid for with cash received from the sale of vegetable or animal products raised on the farm. The isolated farmstead is, nevertheless, the individual cell out of which America's rural settlement structure is composed. It is such a tiny focus, however, that it is incapable of exerting an important centralizing influence as does the rural village, for instance.

AGGLOMERATED OR COMPACT SETTLEMENTS

768. As stated earlier, houses and streets in various combinations of number and pattern comprise the essential elements of all types of compact or collective settlements, from the rural village to the largest metropolitan center. As soon as houses become grouped the necessity is immediately created for intercommunication between them, so that more or less clearly defined streets become necessary, and the spaces between the buildings become relatively regular.

Not only is the street system within the settlement a conspicuous and essential element, but beyond the boundaries of the town proper its centripetal influence is clearly marked by the road pattern. Each agglomerated settlement becomes a focus of transport lines, for one of the prime functions of towns and cities is their market services. In fact, highways (roads, canals, rivers, railroads, steamship and air lines) together with the things that flow over them—human beings as well as goods—have very likely created a majority of the towns and cities now in existence.

769. Two Classes of Compact Settlements. Two principal classes of compact settlements are here recognized: (*a*) those which are essentially rural in aspect and function and (*b*) those the functions of which are largely nonagricultural or urban. In the first group are *rural villages*, the residents of which are chiefly tillers of the soil. Such a settlement primarily is concerned with the production of agricultural goods. Within the second, or urban, group are *cities*, the inhabitants of which "have no immediate interest in the production of the materials for their food or clothing but are engaged in transporting, manufacturing, buying, and selling these materials or in educating the people or in managing the affairs of the state or in merely 'living in town' " (Aurousseau). As a usual thing also, urban settlements are more closely built up, so that there is a denser population per unit area than in the rural villages. Included within the large and diverse group of urban settlements, here designated under the general title of cities, are included such small ones as hamlets and villages, those of intermediate size commonly spoken of as towns, as well as the cities proper.

The Rural Village

770. Nature and Development. In the rural hamlet or village type of settlement, which is the commonest form over a large part of the earth's surface, farmsteads, instead of being isolated as they are in the United States, are grouped together into relatively compact communities. In such villages the predominant, sometimes almost exclusive, group is farmers. To be sure there may be some artisans, tradesmen, and professional men, but usually they are greatly in the minority. The rural village therefore is principally a place of residence and not primarily a business center. It is composed chiefly of farm dwellings and their associated outbuildings.

Community living probably is as ancient as the human race and represents an instinctive drawing together of peoples for cooperative efforts in defense, work, or some other activity. Some sort of locality groups existed even among nonagricultural tribes. Genuine village life arose, however, with the beginnings of agriculture, and there is abundant evidence that men have lived in village groups in Europe and Asia since early Neolithic times. Among primitive agricultural peoples the village was not fixed at one site, for agriculture was often of the shifting type, with moves sometimes as frequent as every two or three years. In these shifting communities the women did most of the work in the fields, with the use of only hand implements and without the aid of domestic animals. Commonly the primitive village was composed of a group of kinsmen.

At a later stage, when agriculture became more permanent, the village became fixed in its location. A definite area of land with fixed boundaries was recognized as belonging to the village. Domesticated animals were employed in conjunction with the plow and the cart, which resulted in men instead of women doing the larger part of the work. Irrigation, manuring, and the feeding of livestock became common practices. Control of the land was at first vested in the village group, or, as in the manorial villages of England, in the lord of the manor. Personal ownership of land was a matter of gradual evolution. The arable land was cultivated by individuals, while the pasture, forest, and waste land was held in common by the village and was used in common.

In modern agricultural villages the land is permanently owned by families or individuals, and common land is rare. The individual farms, however, are still composed of numerous small unfenced parcels scattered in various directions and at various distances around the village. Unlike an American farm, which is usually composed of a contiguous block of land, the farm of a villager in Europe or Asia is composed of several small, unfenced, noncontiguous plots. The latter is known as the *open-field system* of agriculture. It is usually associated with the village type of rural settlement.

771. *The Latifundium Type of Rural Village (Hacienda, Plantation, Finca, Estate).* Throughout certain parts of the world there is a type of compact rural settlement that differs in certain fundamentals from the typical farm village. This type of clustered settlement, designated here as *latifundium,* is associated with extensive agricultural estates, often of thousands of acres, where large numbers of hired laborers are necessary to carry on the ordinary work of the estate. The tea and rubber plantations of the British and Dutch in various parts of tropical southeastern Asia (Malaya, Ceylon, Burma, India, Java, Sumatra, and others) and the haciendas of Latin America are of this type. In the United States the larger sugar-cane plantations of Louisiana have a village type of settlement. On such extensive farms there is usually a central core area that contains the more pretentious homes of the owner and his white overseers, together with the more numerous and modest huts or cabins of the native laborers.[1] In addition there may be a commissary or store and perhaps a school, hospital, and church. Such a settlement is not composed of a group of independent men, owning and cultivating their own homes and land, as is true of the modern agri-

[1] Some plantations are operated by sharecroppers or tenants rather than by hired laborers under an overseer, and under such an organization no central community is required.

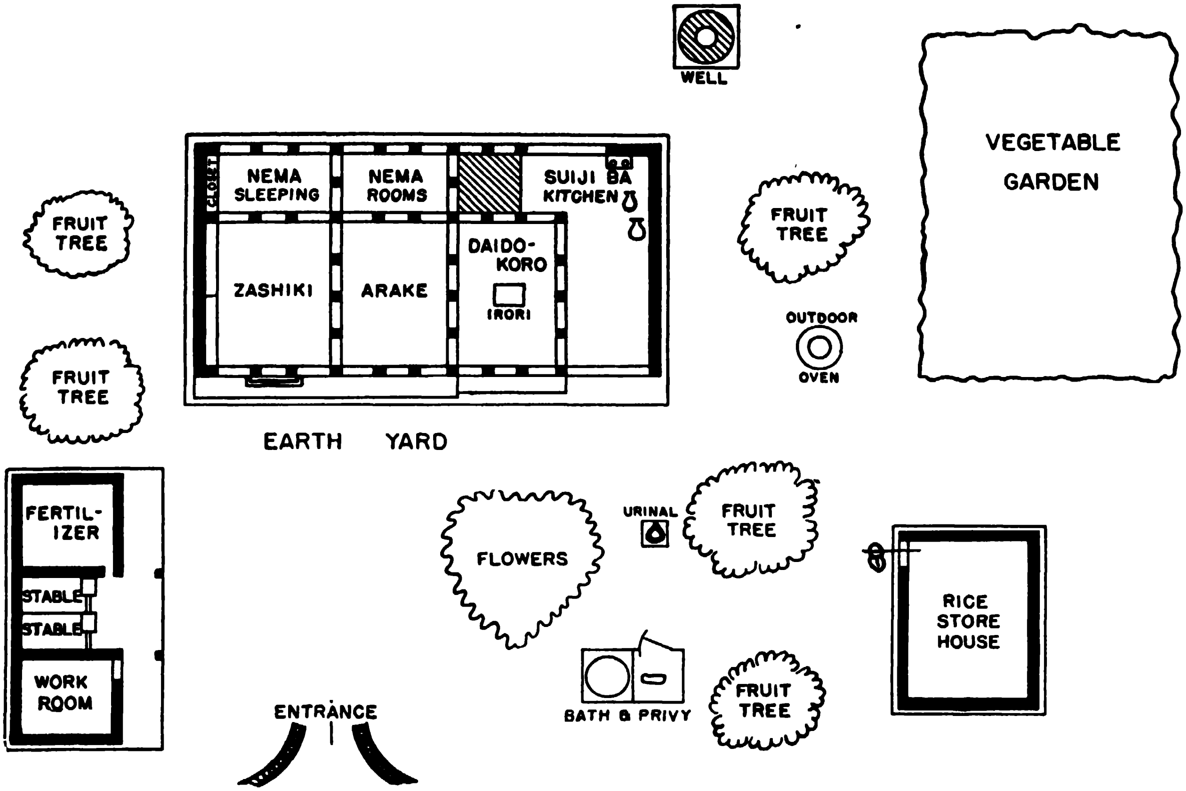

Fig. 403. Plat of a Japanese farmstead. (*Redrawn from a map by John Embree in "Suye Mura." University of Chicago Press.*)

cultural village. The plantation is like a factory, being organized to produce commercially a particular product or crop. As a result the plantation settlement is composed of buildings owned by the estate and rented to the laborers. The latter usually are not closely attached to the land so that they may not stay long at one place. Such a settlement therefore usually lacks the permanency and close social bonds characteristic of the genuine agricultural village. The latter has its life and institutions developed by the people in the village; in the plantation, settlement life is closely regulated by the estate owner. The following description is of a coffee plantation community in the state of São Paulo, Brazil:

A characteristic group of estate buildings is associated with the cultivation of coffee. The most important building is the manager's dwelling, surrounded, at least in the older part of the state, by well-kept lawns and shrubs. Near by are the stables for the estate animals, the sheds for storage, and the extensive tile or concrete platforms on which the crop is spread to dry in the sun. And also near by are the rows of laborers' cottages which betray in their untidy and cheerless appearance the temporary nature of the relationship between owner and tenants. This group of buildings constitutes the *fazenda* and amounts to a rural hamlet in an area of agglomerated population.[1]

772. Distribution of the Village Type of Rural Settlement. The farm village is the characteristic type of rural settlement throughout most of Latin America, Africa, and Asia. Certain exceptions to this generalization have already been pointed out in the discussion on dispersed farmsteads. Europe shows a complicated intermingling of the dispersed and agglomerated types, with Soviet Russia being the largest contiguous area where the village type strongly prevails. In somewhat less dominant form it is also characteristic of Mediterranean, central, and northwestern Europe, except in the regions

[1] Preston E. James. The Coffee Lands of Southeastern Brazil. *Geog. Rev.*, Vol. 22, pp. 225–244 (236), 1932.

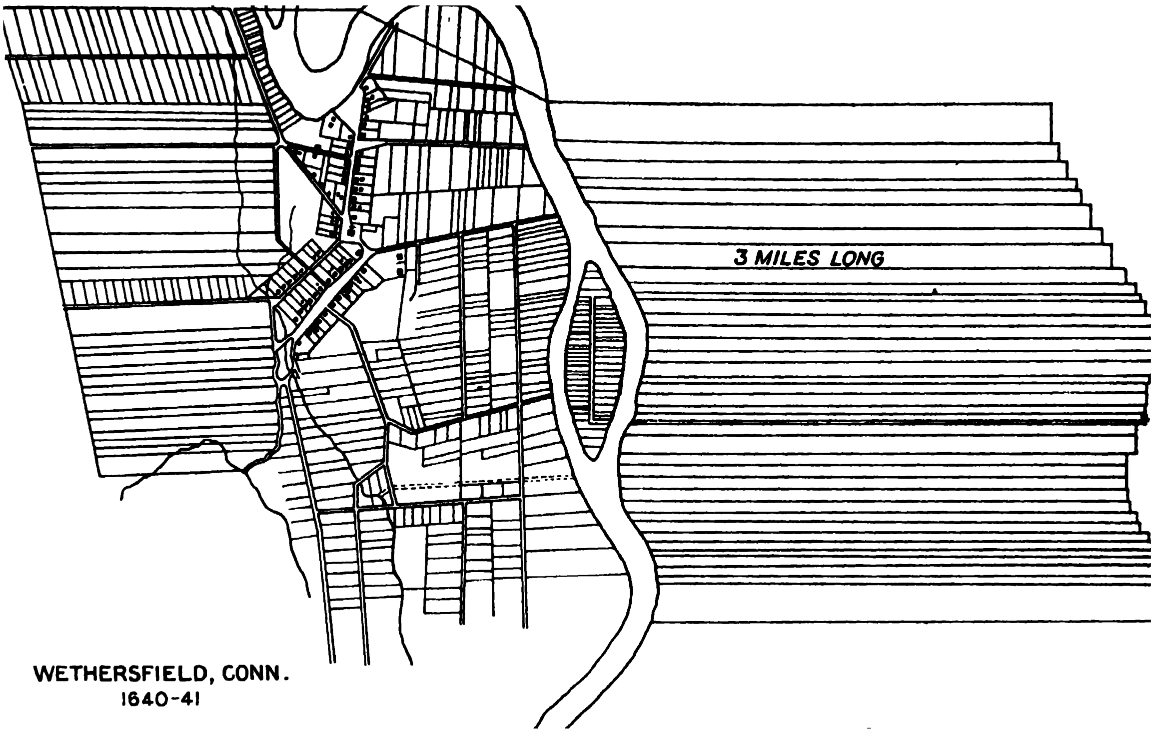

Fig. 404. Plat showing home lots and fields in a colonial rural village in New England.

mentioned in Art. 766. Aboriginal settlements on the Arctic plains of North America are chiefly agglomerated.

773. *The Agricultural Village of Colonial New England.*[1] Although in the United States at the present time the farm village is a rare exception within the standard pattern of isolated farmsteads, this situation was not true during the early history of the country. For the first hundred years and more of its history rural New England was a land of village-dwelling farmers (Fig. 404). In part this compact type of rural settlement had its origins in the need for protection against the Indian menace. In part it reflects the nature of New England's colonization, which was by organized communities and not by individuals. Often the colonizing group had previously existed in England as a church congregation or neighborhood, so that the colonists arrived in their new home motivated by common aims and ambitions and relatively homogeneous in political and social character. Moreover, it was the policy of the New England colonizing companies to make grants of land to groups rather than to individuals. Land was not sold, but instead was awarded to responsible groups desirous of establishing a home in the wilderness. Once the community was established, Puritan ideals of religion and education tended to hold it together. The school and the meetinghouse were the standard focal centers of the New England farm village.

The New England town or township was a grant of land 4 to 10 square miles in extent. Usually somewhere near the geographical center of the town the village was established, with a *common* or *green* as its nucleus. Fronting upon the common and upon the main street were the church, school, and burying ground, together with the home lots of the original settlers. The home lots contained not only the farmhouse but in addition barns and other outbuildings, a garden, and enclosures for feeding livestock and

[1] Glenn T. Trewartha. Types of Rural Settlement in Colonial America. *Geog. Rev.*, Vol. 36, No. 4, pp. 568–596, 1946. Edna Scofield. The Origin of Settlement Patterns in Rural New England. *Geog. Rev.*, Vol. 28, pp. 652–663, 1938.

raising corn. The compactness of the village depended to a large degree upon the size of the home lots. Usually they varied between 1 and 5 acres in extent.

The farm of each villager was composed of several small tracts of land lying in different quarters of the town. The arable lands and mowing lands were divided into large fields of several acres, which were subsequently partitioned into strips and distributed to the settlers by lot. As a usual thing the strips were of much the same size and shape so that an orderly and regular arrangement was very conspicuous. In addition to the home lots and planting fields that were owned individually, there were also the common lands possessed and used by all the original settlers. Pasture and woodland at first were held entirely in common. And although the small planting lots were privately owned they were subject to town regulation relative to choice of crops, and they became common land for pasture after the harvest. Farms varied considerably in size and composition, but on the whole they were not large. In Hartford, Conn., the first distribution of land resulted in holdings of 27 acres, in New Haven, 44 acres. In Groton, Mass., each settler held on the average 59 acres of planting land separated into two or three parcels and 19½ acres of meadow divided into five parcels.

Although Puritan New England was the arch stronghold of the community type of rural settlement in Colonial America, it was not unknown in other sections. For the first decade or two in Virginia stockaded communities were almost the exclusive form of settlement. In Georgia experimentation with carefully planned farm villages continued for even a longer period. In the course of a relatively short time, however, the community type of settlement in the South disintegrated and was absorbed into the plantation system, which became the dominant form of agricultural organization. Beyond the Appalachians in what is now Kentucky and Tennessee the first settlements were by groups occupying stockaded posts called *stations.*

774. The Modern American Village Not Rural. In the United States the counterpart of the European and Asiatic agricultural village of a few score or hundred farm residences can scarcely be said to exist. Since most of America's rural population is in isolated farmsteads, even a small compact settlement of a few hundred inhabitants is likely to be composed largely of shopkeepers, artisans, and professional men, with very few farmers among them. They are chiefly places of business. Most American "villages," then, as far as function is concerned, are urban, not rural. Thus in Montfort, Wis., a village of about 600 inhabitants set down in the heart of an important agricultural area in southwestern Wisconsin, more than one-half of the population is dependent upon income from retail merchandising. Most of the others are supported by the professions, by the railway, and by other types of transportational and communicational services. Hardly a score of the 125 families may be classified as retired farmers, and certainly less than half a dozen are active farmers.[1] Such a community is fundamentally a trading center for the farmsteads of the surrounding countryside. Even an American crossroads hamlet of only a score of dwellings is largely made up of nonfarm families, although it is not unusual for such a settlement to have a few farmsteads. The hamlet, therefore, is relatively more rural than the somewhat larger village.

775. *Some Examples of Rural Villages in the United States and Canada.* The most perfect community type of rural white settlement in Anglo-America is the Mormon farm villages in Utah.[2] Most of the farmers of Utah do not live on their farms, but within villages from which they commute to one or several fields outside the village. This community form of living resulted from a planned mode of agricultural settlement established by the Mormon Church

[1] V. C. Finch. Montfort: A Study in Landscape Types in Southwestern Wisconsin. *Geog. Soc. Chicago, Bull.* 9, pp. 15–44, 1933.

[2] Chauncey D. Harris. Salt Lake City: A Regional Capital. Ph.D. Dissertation, University of Chicago, 1940, pp. 42, 117–121. Lowry Nelson. The Mormon Village: A Study on Social Origins. *Proc. Utah Acad. Sci.*, Vol. 7, pp. 11–37, 1930.

during the middle decades of the last century. It was admirably suited for defense against the Indians and for the social and religious contacts that the church desired. The farm villages are laid out in rectangular pattern, most of them having a central square on which is located the church or tabernacle. In a representative village such as Escalante (1,000+ population), the usual 5-acre blocks are divided into four home lots of 1¼ acres each on which are located the farm home, together with barns, corrals, pens, and sheds. Farms are usually small, their average size in the Wasatch Oasis being only 37 acres. The average distance from the farmsteads to the scattered parcels of land composing the farms is 2.3 miles. It is significant to note that in the newly developed irrigated areas in Utah the isolated farmstead is more common than the farm village, and even in the longer settled areas dispersion is the newer mode of settlement.

At Amana in eastern Iowa is a group of seven farm villages housing nearly 1,500 persons who comprise the Amana settlements.[1] Like the Mormon villages, these of Iowa are the product of a planned mode of settlement by a religious sect. Each village has its own fields, supervised by a farm manager who allocates the labor for the village and decides on the crops to be grown in given fields. Community barns, sheds, and silos serve to store crops and farm machinery and to house livestock.

Somewhat intermediate between genuine dispersion and agglomeration is a type of rural settlement associated with long-lot farms. Under this arrangement, because of the narrowness of the farms, the closely spaced farmsteads along a single street or highway give the appearance of a loose village organization. French settlement in the Lake St. John Lowland in Canada[2] and in the Mississippi Delta is prevailingly of this type. In the Lake St. John Lowland farm lots are ⅛ mile wide and 1 mile long with the narrow side facing the highway. In certain parts of

[1] Darrell H. Davis. Amana: A Study of Occupance. *Econ. Geog.*, Vol. 12, pp. 217–230, July, 1936.

[2] Robert M. Glendenning. The Distribution of Population in the Lake St. John Lowland, Quebec. *Geog. Rev.*, Vol. 24, pp. 232–237, 1934.

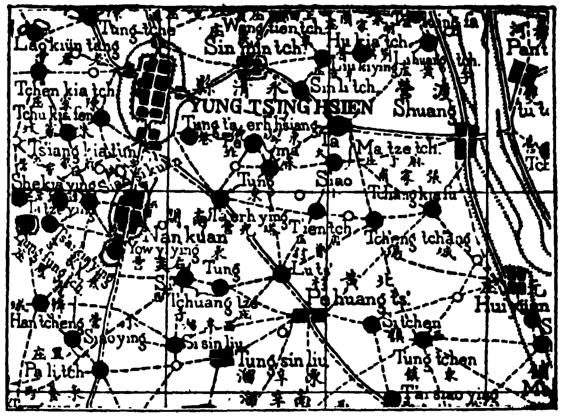

Fig. 405. Rural hamlets and villages (black dots), together with market towns, on the North China Plain. (*From Carte de la Chine, Sheet 202. Scale about 1 in. = 2½ miles.*)

New England likewise, farmsteads are so close together along highways as to give the appearance of community settlement.[3]

776. *Rural Villages of the Far East.* The compact farm village is the basic unit of settlement in eastern and southeastern Asia, where nearly one-half of the earth's population is concentrated. Thus in China, where at least 80 per cent of the 450,000,000 people are dependent upon the land, 88 per cent live in settlements having fewer than 10,000 residents, while the most fundamental unit is the farm village of 250 to 2,500 people (Fig. 405). In Japan, where nearly 45 per cent of the 81,000,000 inhabitants are dependent upon agriculture, over 44 per cent of the total reside in the 9,600 rural settlements having fewer than 5,000 citizens. Nearly 20 per cent more live in villages or towns having between 5,000 and 10,000 inhabitants, and these are predominantly rural as well.

The basis of Chinese civilization is the village community (Fig. 406). Many of these villages are family villages, being composed of families all bearing the same surname and tracing their descent from a single ancestor. The units of the village are not individuals but families. Each member lives and works not for himself but for the family to which he belongs. Each family

[3] Edna Scofield. The Origin of Settlement Patterns in Rural New England. *Geog. Rev.*, Vol. 28, pp. 652–663, 1928.

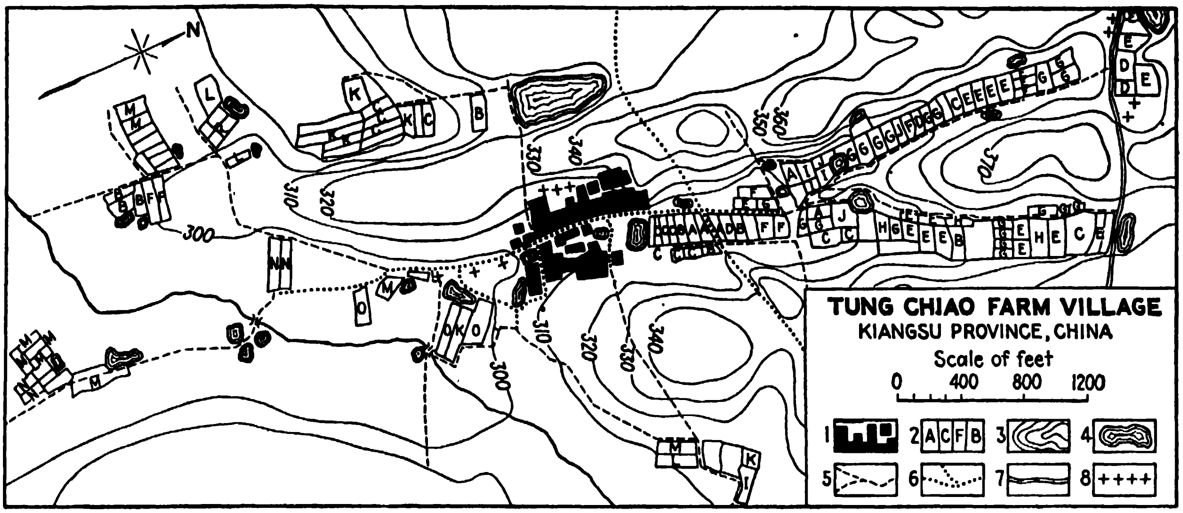

Fig. 406. A representative Chinese rural village and its associated fields: 1, the village; 2, field plots (all marked *A* are tilled by Farmer A, those marked *B* by Farmer B, etc.); 3, hill lands, usually in grass and groves (contour figures are in feet); 4, ponds for irrigation and fish; 5, earth paths; 6, paths paved with stone slabs; 7, paved road 7 ft. wide; 8, Buddhist temples. (*Original map by John L. Buck. From Jones "Economic Geography," by permission of The Macmillan Company.*)

owns its own lands, possesses certain rights in the common land, and shares rights and responsibilities connected with the upkeep of the ancestral temple and the burial ground. Sometimes the village proper is separated from its fields by a wall as a protection against bands of plunderers. A Chinese village is a physical and cultural feature. Throughout 500 years of modern history it has changed little. The houses are like those occupied by the ancestors of the present villagers half a millennium ago. The descendants are doing what their ancestors did, cultivating the same fields in the same way, going to the same markets, following the same customs and habits. The Chinese farm village has few shops, and those that do exist carry a very limited supply of goods. Trading is done chiefly at the market towns. In the smaller farming villages there are practically no artisans, for the farmer is blacksmith, carpenter, and architect as well.

In Japan the ubiquitous farm village[1] is striking in two respects: (*a*) it is a social unit to a degree unknown in the Occident, and (*b*) the well-being of the villager is not primarily expressed in money. Tiny shops, each specialized in a single class of goods such as fish, tobacco, cakes, cloth, etc., occupy the front rooms of a few residences. These goods cost money, but they are bought not so often with cash as with rice. In other words the village still exists to a considerable degree in the rice-money economy of the fourteenth to sixteenth centuries. An almost unbelievable frugality characterizes the living of the villagers, but this keeping alive on the very cheese rind of existence is made endurable by the close communal life of the village unit. They play and work together so that life in the village is attractive and warm in spite of its incredible meagerness (Fig. 407). It is this willing frugality of living on the part of Japan's large agricultural population that is one of the country's greatest bulwarks, keeping industrial wages at a low level and thereby permitting the Japanese exporter to compete with those of nations with greater natural resources.

777. Village Patterns. Villages differ greatly from one another in shape and pattern by reason of contrasts in the arrangement of streets and their houses. These contrasts are sometimes the result of the physical character of the land on which the settlement is built (its site), but equally often they are associated with historical causes. For example, a river levee

[1] John F. Embree. "Suye Mura, A Japanese Village." University of Chicago Press, Chicago, 1939.

or a beach ridge along a coast may induce an elongated, or "shoestring," type of settlement with the houses laid out on either side of a single principal road or street which follows the crest of the ridge. This type of village is very common in Japan on the wet inundated lowlands where floods are frequent and consequently elevated dry sites offer some protection. On the other hand, when a settlement originates at the crossing of two main highways meeting at right angles on a plain, the village is likely to be more compact in form with its streets laid out in rectangular pattern conforming to that of the main highways. In hilly regions of uneven surface configuration, winding roads following stream divides or valley bottoms may induce very irregular and complicated street arrangements. Sometimes it happens that the original houses of a settlement were built before any road pattern developed, each house occupying what seemed to the owner a favorable site. Later, when a street system emerged, it was of necessity irregular and almost without plan. In South China, where animal-drawn vehicles are absent, village streets are narrow, crooked lanes. In North China, on the other hand, where animal-

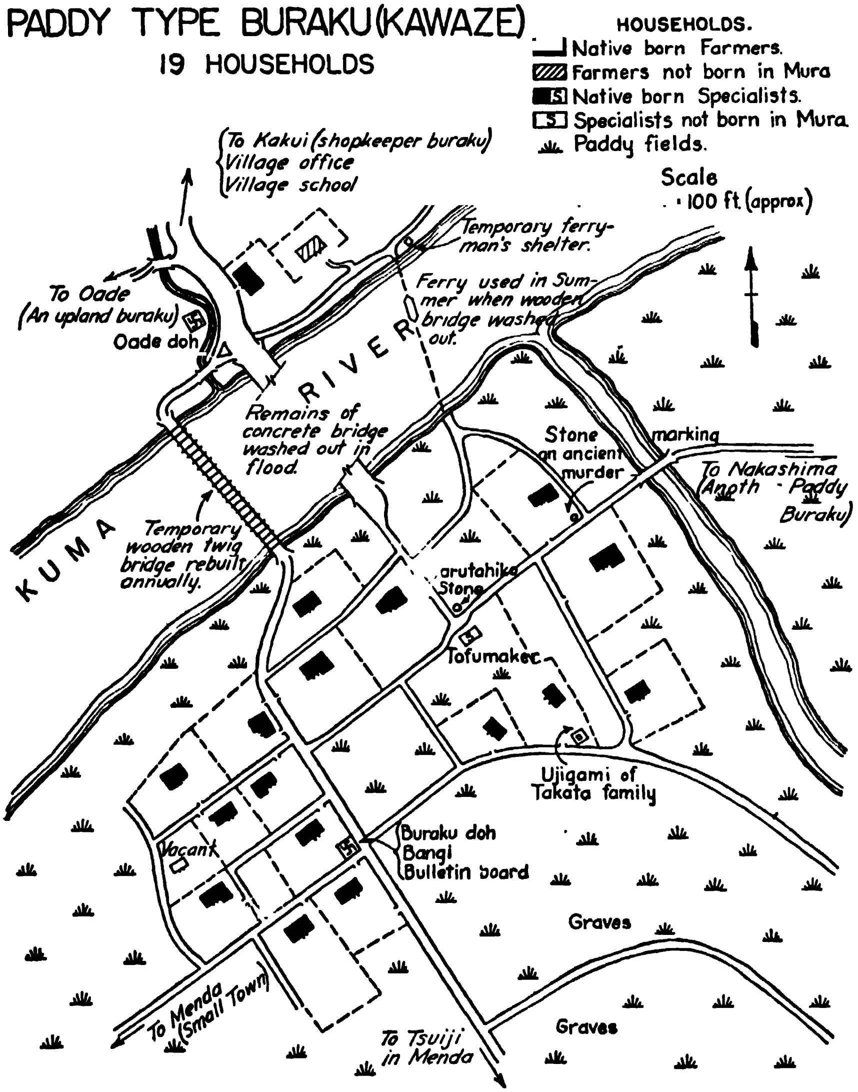

Fig. 407. A Japanese farm village. (*After map by John Embree in "Suye Mura," University of Chicago Press.*)

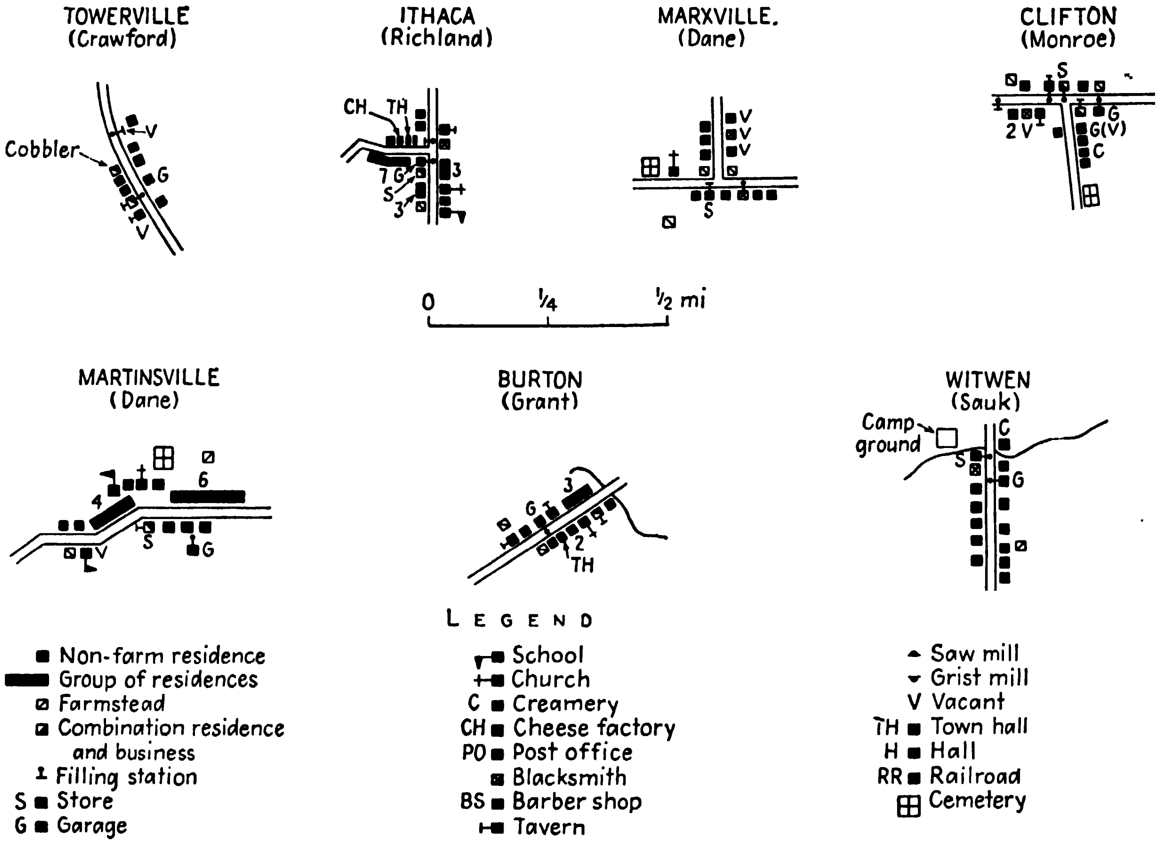

Fig. 408. Wisconsin hamlets.

drawn carts are common, streets are fairly wide and straight and have a rectangular pattern (Figs. 356, 373, 409, 410, and 411).

URBAN SETTLEMENTS

(Hamlet, Village, Town, and City)

778. Definition. Although rural settlements may be either dispersed, such as isolated farmsteads, or compact like farm villages, urban settlements, on the other hand, are always compact or nodal in character. In the rural settlements the concern is chiefly with primary production, most commonly agriculture. In urban settlements, on the contrary, the primary goods produced by the farmer, miner, or lumberman are processed in manufacturing plants, transported, bought and sold, and financed. These are secondary forms of production. In addition towns perform educational and political functions. Urban settlements in ascending order of size and complexity are hamlet, village, town, and city. There are no very precise definitions differentiating these four types of urban settlements.

779. The Unincorporated Hamlet.[1] Of the compact nucleated settlements in the United States having significant urban functions, the unincorporated hamlet is the smallest and least conspicuous. It is neither purely rural nor purely urban, but a combination of both, with the latter functions predominating. In population the American hamlet usually ranges from 20 to 150 inhabitants. The founding of these tiny settlements was almost contemporaneous with the coming of settlers into a region. They developed as service centers and social centers for the surrounding farm areas. Rarely are they purely residential settlements and commonly

[1] Glenn T. Trewartha. The Unincorporated Hamlet. *Ann. Assoc. Amer. Geographers*, Vol. 33, No. 1, pp. 32–81, March, 1943.

they contain one or more of the following other functional units: post office, church, school, general store, cheese factory, feed mill, tavern, filling station, garage. It is a usual thing to have several of these functions combined in one establishment. Where the total volume of business is small, as it must be in a hamlet, it seems a natural thing for several types of business to be integrated under one proprietor and housed under one roof. Moreover, the residence is not uncommonly also a place of business. In a study of 167 hamlets in southwestern Wisconsin it was found that over 9 per cent of the residences have some sort of business enterprise connected with them. The fundamental function of the American hamlet, the tiniest of compact settlements, is that of a commercial service center for the buying and selling operations of the surrounding farm population (Fig. 408).

The families who reside in an American hamlet are largely nonfarmers. On the other hand, it is by no means uncommon for a hamlet to contain one or more farmsteads, each with its collection of barns, sheds, windmill, silo, and cattle and hog yards. In Wisconsin some 12 per cent of the residences in hamlets are farmstead dwellings. This is not to be wondered at when one considers how near to being rural these little settlements are. Urban squeamishness to barnyard odors has not developed to the point where these things seem particularly objectionable. It is probably good for the hamlets to number active farmers among their citizens and to be in close physical proximity to farmsteads. The result will be to keep hamlets rural-minded, a feature which is not true of the larger villages and towns which tend to face away from the country and to envy and imitate the city.

780. Functional Areas in the Market Village and Town. In the agricultural village composition is relatively uniform throughout, the settlement being composed of farm residences and associated shelter and storage sheds. Usually no "business section" exists, although

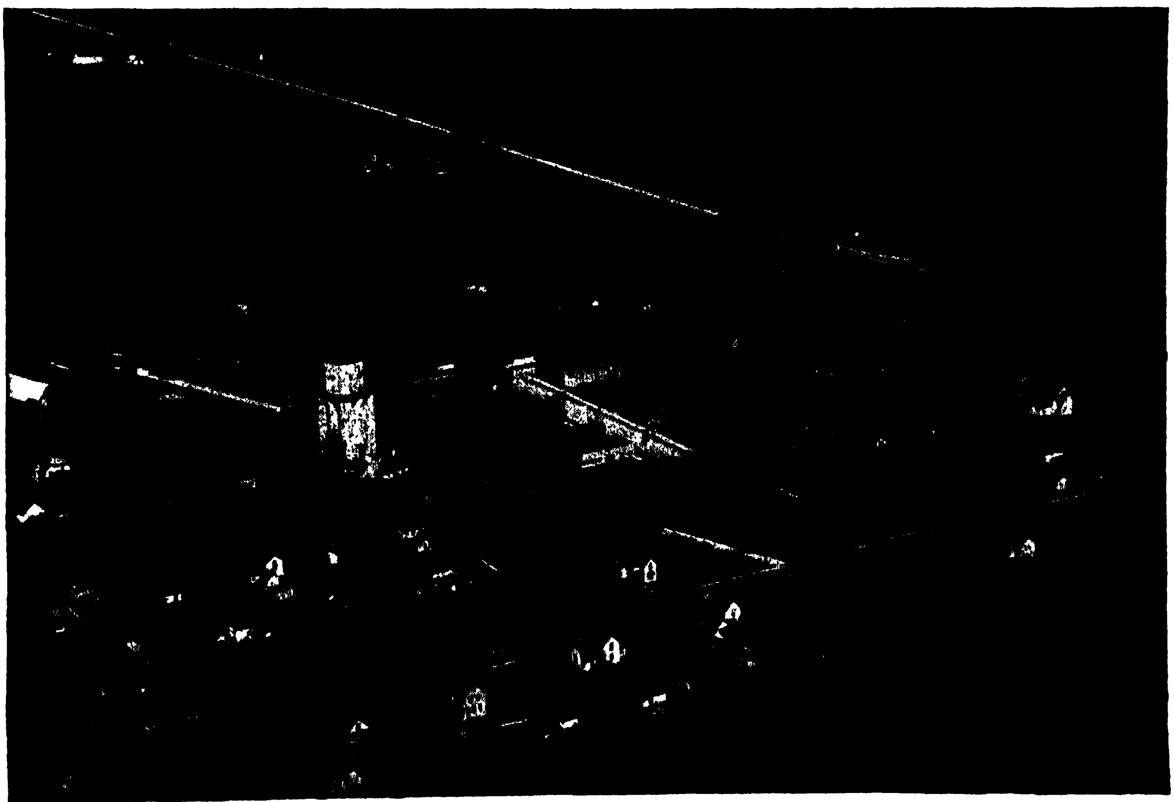

Fig. 409. Aerial view of a small Illinois market town with isolated farmsteads in the background. (*United Photo Shop.*)

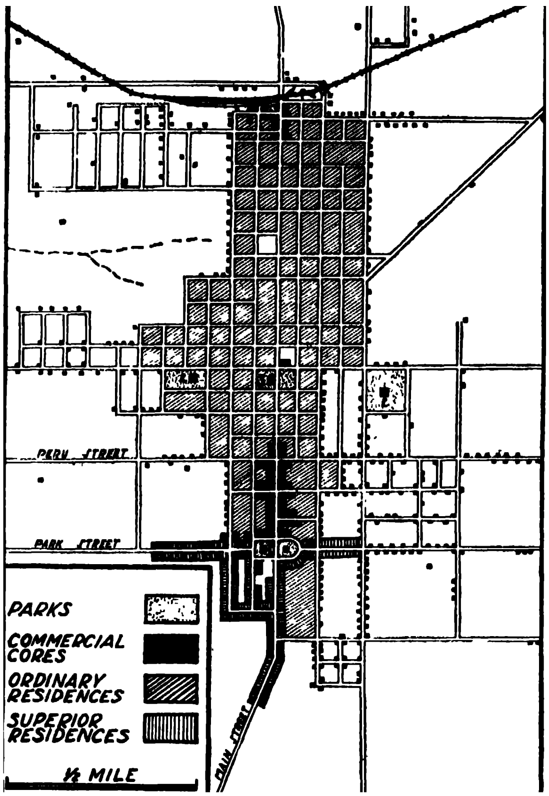

Fig. 410. Arrangement of functional areas within a market town. The town has grown northward toward the railroad where a secondary business core has developed. (*Map by Stanley S. Dodge.*)

there are often scattered shops. In the market village and town, on the other hand, where urban functions usually predominate, there are almost certain to develop distinct and specialized *functional areas.* The two that stand out prominently in almost any market town are (*a*) the commercial core, or business district, and (*b*) the residential portion (Figs. 409, 410 and 411). It is in the former, where shops and stores predominate, that urban functions are concentrated. The commercial core may be distinguished from the residential area, not only by the *kind* of buildings but also by their *spacing.* In the former the structures often abut against one another, while the residences are likely to be farther apart. Other functions, such as manufacturing, government, education, and recreation, may be represented in the market town, but usually they are not segregated into distinct areas of conspicuous size.

Like the rural village, the town may be cast in a variety of shapes and patterns, both externally and internally. One of the commonest arrangements is that in which the commercial core lies somewhere near the geographical center of the town with residential areas surrounding it on all sides. Thus while the rural village has no distinct nucleus or center, this becomes a characteristic feature of cities and towns.

The City

781. Cities, the Focal Points in Man's Utilization of the Earth. The city represents the most complete modification of a portion of the earth's surface that man, through his constructive and destructive contacts with that surface, has been able to make. There human beings are crowded together in greatest numbers and density, and, partly as a result of this concentration and intensive occupying of the surface, man has there brought together his mightiest assemblage of material-culture features. So complete is the culture cover that it tends to mask, and at the same time greatly modify or possibly obliterate, the original natural features of the site. Even beyond the margins of the city proper, the settlement makes itself felt in an intricate network of communications, for these routes represent the necessary lines of contact with the countryside that it serves and that supports it. Through these channels pass tremendous quantities of food and raw material to be consumed or otherwise used by the city organization, and it is along these same routes that the city's products feed back to the surrounding countryside. "The city creates the road; the road in its turn creates the city, or recreates it. . . . "

While each city is unique and has individuality in the details of its arrangement and form, it has, on the other hand, much in common with other cities in many aspects of its appearance and development. Thus cities of similar size and function and in the same general regional setting tend to duplicate each other in general internal structure. This makes possible certain broad generalizations about cities.

782. What Supports Cities? Cities do not grow by themselves. They are set up by countrysides to do the tasks that must be performed in central places. They are the head offices. They cannot exist in isolation, for the primary support of a city is not in the services that it performs for itself, but for the surrounding tributary area. To be sure, the function of grocers, barbers, bakers, and many other businessmen in a city is to serve the city dwellers, the great mass of whom, however, are engaged in the primary activities of the cities which may be trade, manufacturing, education, or government.

The services which a city renders and by which it supports itself depend to a large extent upon the nature of the hinterland, its resources, and the character of its economy. In regions of meager resources or of primitive or self-sufficient economy, cities are likely to be few and small, for there must be a surplus from the land in order to support a city. This by no means indicates that a city is a parasite living off the surrounding countryside. In a modern complex civilization with regional specialization and an interdependent economy much of the necessary economic life is incapable of being carried out in the open countryside but instead must be concentrated in cities. In such a civilization cities are equally as essential as are the farmers, miners, and loggers who produce the primary goods.

The table on page 566 attempts to classify cities and towns according to their dominant functions. The descriptive terms used in the table are self-explanatory. Illustrations of each type can easily be called to mind. Of the several classes of cities listed, some were more important in ancient civilizations, while others, such as Class IV, manufacturing, and Class V, commercial, are characteristic of modern industrial economies.

783. Cities of the Past. Cities and urbanism are by no means exclusive to the modern era of factory industry and efficient transportation. In the two world centers of ancient civilization and culture dispersion, eastern and southern Asia and the eastern Mediterranean Basin, cities appear to be as old as the civilizations themselves. The oldest city of which we have any record is Memphis, the walled capital

Fig. 411. Business section of an American market town, Prairie du Chien, Wis.

Classification of Urban Groups According to Dominant Functions
(After Aurousseau)

Class I Administration	*Class II Defense*	*Class III Culture*	*Class IV Production (Manufacturing)*
Capital cities Revenue cities	Fortress cities Garrison towns Naval bases	University towns Cathedral towns Art centers Pilgrimage towns Religious towns	Manufacturing cities Craft towns

Class V Communication (Commerce)			*Class VI Recreation*
Group A Collection	*Group B Transfer*	*Group C Distribution*	Health resorts Tourist resorts Holiday resorts
Mining towns Fishing towns Forest towns Depot towns	Market towns Fall-line towns Break-of-bulk towns Bridgehead towns Tidal-limit towns Navigation-head towns	Export cities Import cities Supply cities	
Entrepôt cities			

of ancient Egypt, which was in existence as early as 2500 B.C. Somewhat later the capital cities of Babylon and Nineveh flourished in the valley of the Tigris and Euphrates Rivers. For ten centuries, and up to about 500 A.D., city life followed the shores of the Mediterranean Sea. Tyre and Sidon, capitals of ancient Phoenicia, were especially famous as port cities. The Greek cities of Athens, Corinth, and Syracuse were not only local capitals and defense towns, but they were urban centers in the modern sense as well, with a high degree of economic vitality. Carthage and Rome, likewise capitals, were hives of industry and trade.

Following the collapse of Rome and with the invasion of the barbarian tribes, cities were sacked and pillaged and for five centuries or more urban life in Europe declined. Those which continued to exist were much reduced in population and eked out a miserable and isolated existence. From about the eleventh century on cities began to revive in Europe. This in part was stimulated by the Crusades. Italian cities, such as Firenze (Florence), Genova (Genoa), Venezia (Venice), and Pisa, were among the first to feel the effects of the revived trade. The medieval Hanseatic cities of Germany similarly were supported chiefly by trade.

Cities in China, although not so ancient as some of those in the Mediterranean Basin, certainly antedate by several centuries the beginning of the Christian era. To an unusual degree ancient Chinese cities were political centers although, to be sure, they performed economic functions as well. The Chinese concept of a city was not that of a large number of people residing within a restricted area, but rather it was the official residence of a public officer and the visible evidence of a city was the encircling wall. The rank of a city was determined not by size but by the rank of the public official residing there. This rank was conspicuous in the name of the city. If the name ended in *fu* the city was of high rank; if it ended in *ting* or *chow* it was of lower rank. Both in the Mediterranean Basin and in the Far East, then, it is evident that original location and subsequent growth of cities was associated with political and defense considerations. In modern cities, however, these items have had little to do with the location and growth of great urban communities. Only a few of the world's great cities are political capitals, and probably none of them has defense value. In the nineteenth and twentieth centuries city development has been largely dependent upon industry and trade.

784. Modern Cities: Functions and Locations. In regions where a relatively large proportion of the population lives in cities, it is

usually indicative of a relatively advanced stage of material civilization—a stage that many regions of the world have not yet reached. In all periods of world history the city has represented the vanguard of intellectual progress and culture. With the city came division of labor and the necessity for economic surplus, and out of this came leisure, wealth, development of the arts and sciences, and general intellectual advance. It has been said that steam, steel, and credit have made the modern large city possible. Transportation and storage made it feasible to keep a million and more people fed with perishable foods. Credit allows one generation to build and the next generation to pay its share of the cost. The modern metropolis, with its single business nucleus, is a product of fast transportation which permits the shuttling of large numbers of people in and out of the downtown section each day. Old cities in Europe and the Far East characteristically had several nuclei.

Most cities have located and developed as a result of more than one causative factor, and the functions they perform are likewise seldom singular. Nevertheless the support of cities and the functions they perform can be classified into three subdivisions: (*a*) Cities as central places performing multiple services, often of a marketing nature, for the surrounding area. (*b*) Transport cities located frequently at break-of-cargo points along transport routes and performing the services associated with such a location. (*c*) Manufactural cities and others of a specialized function type.

785. *Cities as central places* are likely to be distributed rather widely and uniformly throughout a productive area. Where resources are unevenly spaced, the cities are likely to be as well. They are the marketing and social centers for tributary areas of variable size. Such cities vary greatly in size and in the extent of the tributary areas which they serve. They are the standard type and are found widespread throughout most of the nonindustrialized regions of the earth. In the Middle West agricultural region of the United States cities as central places exist as retail and wholesale trade centers. The downtown shopping sections and wholesale districts of such cities contain imposing stores which are supported by the trade of the tributary area. Many central cities and towns combine political and social functions with those of marketing. Thus many state capitals and county seats are likewise central places. In some parts of the world, also, these central places are partly supported by temples, shrines, and churches which attract large numbers to religious and social events.

786. *Transport cities* are a specialized type of urban development, and unlike central places are likely to have an uneven distribution inasmuch as lines of communication, because of terrain and other causes, are not symmetrically developed. Most cities with specialized functions appear to be associated with certain types of strategic locations favorable to urban development, which cause "the seed to spring to life and guarantee its growth." Such cities appear to have had their inception and growth in considerable numbers in at least two kinds of locations: (*a*) adjacent to some obstacle which hindered the further movement of men or goods and made it necessary to halt transport, break cargo, and perhaps find some different means of travel from there on; and (*b*) the convergence or crossing of important trade routes. If a break of bulk is necessary, such a transport focus becomes a desirable place at which to process goods. Especially where the form of transport changes, such as changing from rail to ship or vice versa, a break in bulk is unavoidable. At such points storing, sorting, packaging, and reassembling become necessary. One of the commonest forms of transport city is, therefore, the port which is located at the line of contact between land and water. The great ports of New York, London, and Hamburg are representative of this type of location. Buffalo at the eastern end of Lake Erie is an excellent example of a break-in-bulk city, for there the lake boats carrying wheat transfer their cargoes to rail lines which take it on east. Duluth and Superior at the western end of Lake Superior, where iron ore and wheat arriving by rail are transferred to lake boat,

have a similar function. Some ports such as Singapore and Hongkong act as middlemen and are known as entrepôts. At such points goods are transshipped from small to large ships, or vice versa.

Some transport centers are located so as to serve as gateways to contrasting regions. Minneapolis–St. Paul, Omaha, and Kansas City function as gateway cities between the humid east and the dry west. St. Louis similarly is a gateway to the southwest and Louisville, Cincinnati, and Baltimore to the Cotton Belt. Mountains are still another type of obstacle, the barrier effects of which have nurtured the growth of transport cities. Thus, along the base of the Alps from Wien (Vienna) to Lyon on the north and from Trieste to Torino (Turin) on the south are perfect girdles of cities, many of them located at the plain ends of mountain passes. Arid lands are likewise effective barriers to communication, so that the margins of deserts have their "ports" as do the margins of oceans. After a difficult crossing of these dry waste spaces, caravansaries, where men and animals may rest, obtain food and water, and business may be transacted, are needed. Merv and Bukhara in Russian Turkistan, and Timbuktu on the equatorward margins of the Sahara, are representative of this type of commercial city.[1] At the *end* of a barrier, where routes of travel converge as they are forced to go around the obstacle, are to be found especially favorable conditions for the growth of great trade centers. Chicago, at the southern end of Lake Michigan, is strategically situated, not only because it is at the junction of land and water routes but even more because the lake barrier converges a large number of important land routes toward its southern extremity. Atlanta, Ga., at the southern end of the Blue Ridge Mountains, profits by a similar concentration of land routes.

Istanbul (Constantinople) is a classical example of a city that has prospered as a result of its strategic location at the *crossing* of important trade routes. There the most important land route between Europe and Asia intersects at the narrow Bosporus, the equally important water route leading from southern Russia and the Black Sea to the Mediterranean. In the United States, so much of whose commercial development has taken place within the last century or since the advent of the railroad, city development has been more closely associated with the "civilizing rails" than it has in most parts of the world. St. Louis, Kansas City, Omaha, Indianapolis, and scores of other American cities owe their principal growth to the convergence and crossing of numerous rail routes.

[1] Vidal de la Blache. *Op. cit.* Pp. 473–474.

787. *Manufactural Cities and Others with Specialized Functions.* Like transport cities, those supported by a specialized service such as manufacturing, mining, or recreation are not likely to be evenly spread as are central places. Specialized functions are likely to be associated with a highly localized resource. Sometimes it is a physical resource such as a mineral deposit which localizes a city. Scranton in the anthracite coal field of northeastern Pennsylvania illustrates the point. Long Beach, Miami, and Nice (France) are resort cities which have benefited from their climates, beaches, and ocean views. Once a city has gained fame for a certain specialization, it tends to attract similar and related industries. Thus a specialized automobile-manufacturing city like Detroit attracts other industries which process parts for cars.

Industrial cities not infrequently are also great commercial cities, for they find in those items of location favorable to the *movement* of men and goods features that favor the *processing* of goods as well. Great commercial centers obviously are able to facilitate the assembling of raw materials and the dispersal of finished products, both of which are necessary for factory growth, and the local market and labor supply are additional factors attractive to industrial concentration. New York City, Chicago, Boston, Shanghai (China), and Osaka (Japan) are representative of a large group of cities that are specialized both in the *movement* and in the *processing* of goods.

There are many others, to be sure, which are

more exclusively manufactural in their functions, whose development has not been so closely associated with transport advantages. Without doubt, coal, the principal source of industrial power, has been an item of first importance in the location and development of industrial cities. This relationship between mineral fuel and manufactural centers is nowhere better illustrated than in western Europe, where a high degree of coincidence is evident between coal fields and industrial cities. This is particularly true of urban clusters specialized in heavy industries, such as metals, in which large amounts of heat and power are required. In central and western Europe there is a marked concentration of cities within an irregular belt extending from the Silesian coal field in Poland and Czechoslovakia on the east to that of Wales on the west and including the other coal fields of the British Isles, the Westphalian-Belgian-north France field, and important lignite beds in central Germany. Birmingham, Manchester, Newcastle, Essen, Lille, Liége, Leipzig, and Katowice (Kattowitz) are only a few of the many manufactural cities within the great European coal belt.

Where cheap and easy transport of coal is available, the manufactural city depending upon that source of power may not be located immediately upon the field. Belfast, in northern Ireland, receiving Glasgow and Carlisle coal by boat; Cincinnati with cheap river transport of coal from the Appalachian field; and Gary, Milwaukee, Cleveland, and Detroit enjoying economical lake transport from the same region all are examples of the point in question. The numerous cities of the manufactural belt of the United States (Fig. 430), located in the northeastern part of the country north of the Ohio and east of the Mississippi River, for the most part lie outside any coal field. They have, however, easy access to the coal from the extensive Appalachian Field. Other localizing factors are the Great Lakes which bring iron ore and coal together, productive agriculture, and cheap ocean transportation to the North Atlantic Seaboard. In the last decade or two the increasing use of electric power in industry has had a significant effect upon urban development. Where electricity is generated from coal the generating plants may be located at the coal pits and the power sent wherever needed within a radius of a few hundred miles. The outstanding fact of post First World War industrial development in England was the rapid expansion of the London center so that, although it is removed from any coal field, it has been nevertheless the fastest growing of Britain's large industrial areas.

788. Distinguishing Features of a City. Mere size, expressed in terms either of number of people or of area occupied, is scarcely sufficient clearly to distinguish the city from the market town, although, to be sure, cities are characteristically larger than towns. A much more precise distinction may be made, however, in terms of (*a*) the number of urban functions and (*b*) the number of functional areas (Fig. 412). The small central-place market town usually has only *one* distinct primary *urban* function (commonly market service), which serves more than just the local settlement. If what has been a market town increases its functions, so that in addition to market services it adds those of manufacturing, government, recreation, and others, then it is plurifunctional and so may be characterized as a city. Very obviously along with the expanding urban functions or services there is a parallel growth in complexity of the city structure, with a more complete segregation of particular functions within definite areas. Thus, although the town may have, in addition to its residential areas, a definite business core, the city will have these two and also specialized areas where factories are concentrated or perhaps where warehousing services are developed. As a consequence of the several contrasting functional areas, the city *looks* different in its different parts.

789. *Functional Areas.* Within the downtown business district, tall, closely spaced substantial buildings of brick, stone, and concrete occupied by retail shops and professional offices prevail. This emphatically is the hub, or the nucleus. Upon it the street system converges so that within it traffic is usually congested. Land is so

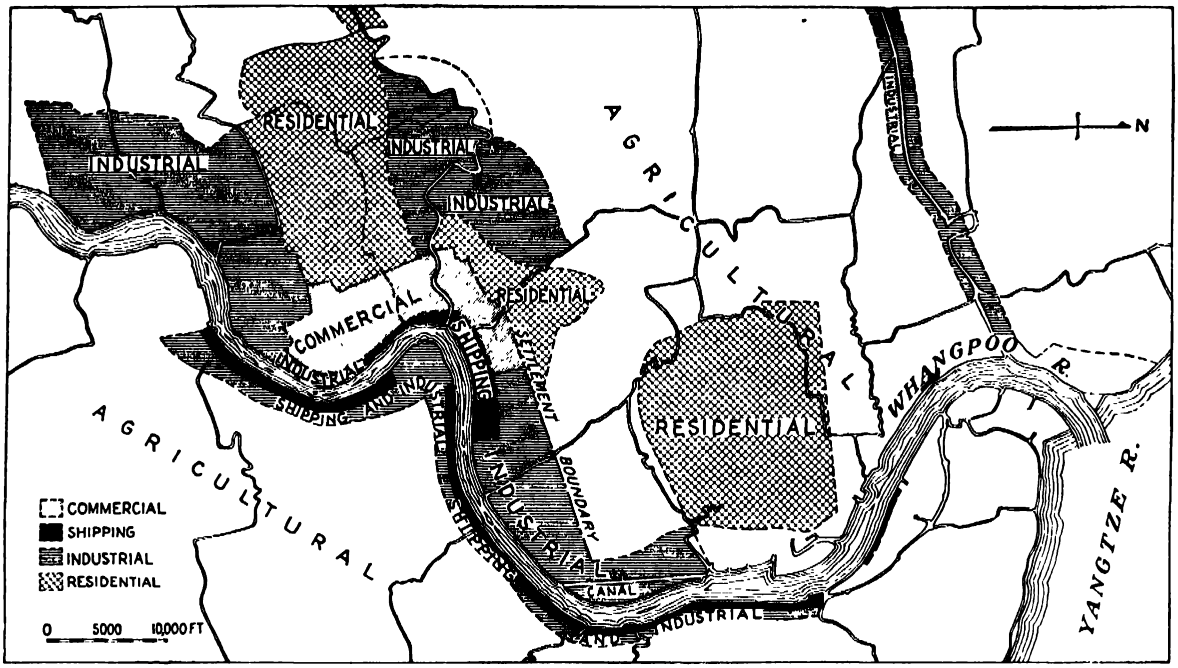

Fig. 412. Functional areas of Shanghai, China.

expensive that buildings tend to be tall instead of broad. It is this portion of the city which usually provides the characteristic urban skyline. Beyond the business core there may be a number of small, scattered, local business areas and likewise numerous single streets given over largely to shops and office buildings.

Wholesale, heavy-retail (lumber, feed, fuel, ice), and storage functions are concentrated outside the business core, where land is more abundant and cheaper. Very definitely this type of business is attracted by rail or water transport facilities which make easy the movement of heavy, bulky commodities. Spur railroad tracks, and boxcars usually are conspicuous. Such business requires much ground space for shelter and storage, while the buildings that it occupies are relatively low and widely spaced. There is a feeling of openness about it which is absent in the business core, and congestion of traffic is less conspicuous. Exclusive manufactural areas are likewise regions of cheaper land and widely spaced buildings surrounded by storage yards and served by spur railroad tracks and canals. Water towers and tall smoking chimneys are characteristic features. Industrial areas have the reputation of being dirty and unattractive.

Residential districts within large cities vary more in quality and appearance than do those of smaller market towns, *i.e.*, greater extremes of poverty and luxury are represented. Some of the least desirable residential districts are those which have been encroached upon by expanding manufactural or business areas so that they have become decadent. The finest and most exclusive residential districts usually occupy attractive physical sites well removed from industrial and business concentrations, as, for instance, along a river or lake or on an elevated spot that provides extensive and attractive views.

790. Distribution of Cities. As of about 1940 there were in all the world 643 cities with over 100,000 population—171 in Asia (excluding the Soviet Union), 291 in Europe (including the Soviet Union), 100 in Anglo-America, 44 in Latin America, 23 in Africa, and 14 in Oceania and Australia. In 1801 there were but 21 such cities in all the world, and all were in

Europe. It would appear as though urbanization was an European process and that Europeanization has been spreading rapidly throughout the world. At first glance the figures for the continents might look as though Asia were one of the most highly urbanized continents and Australia the least, but such is not the case. If, instead of number of great cities, the percentage of the total population living in cities of over 100,000 is used, the picture is markedly different. Australia leads in urbanization with 35 per cent of its people in cities over 100,000 population. United States comes next with 29 per cent, Europe third with 17 per cent.

Urbanization by Continents or Countries

Continents or Countries	Cities of 100,000 or More	Urban Population (Millions)	Total Population (Millions)	Per Cent of Population in Cities
Asia	171	70.2	1,187	5.9
Europe	202	65.9	382	17.3
United States	92	38	131.7	28.8
Soviet Union	89	28.8	193	14.9
Latin America	44	16.8	149	11.3
Africa	23	5.7	173	3.3
Oceania and Australia	14	4.1	12	34.5
Canada	8	1.8	12.3	14.7
World	643	231.4	2,251	10.3

On a world map there are four widely separated regions of outstanding urbanization, where more than one-fifth of the people live in cities of over 100,000. These regions are (*a*) the United States and adjacent small sections of southern Canada, (*b*) North Sea Europe (Great Britain, Germany, Netherlands, Denmark), (*c*) the River Plate region in South America, and (*d*) eastern Australia and New Zealand. Two kinds of regions are represented: (*a*) regions specialized in industry and commerce as well as in agriculture, such as northeastern United States and northwestern Europe, and (*b*) regions that are predominantly agricultural, such as the two Southern Hemisphere regions, where the agriculture is of such an extensive type as to require a small amount of human labor. For this reason an undue proportion of the population resides in port cities supported by trade in agricultural products from the hinterland. In such large countries as the United States there is considerable variation in degree of urbanization in its different parts. Thus while 28.8 per cent of the total population of the United States live in cities of over 100,000, the figure is 37 for the North, 30 for the West, and 13 for the South.

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CHAPTER 30: *Agriculture and Its Associated Features*

791. In its broad sense, agriculture is the most necessary of the world's principal forms of production, and it certainly is by far the most widespread. Agricultural land is likewise the most basic and fundamental of the world's resources. It is from the land that man is fed and clothed, since the manufacturer who processes food and clothing is dependent upon the farmer for the larger part of his raw materials. The agricultural population is also one of the world's principal consumers of manufactured products. So it is that even much of the industrial and commercial development of regions is based at least indirectly upon the land.

792. Agricultural Land. Agriculture requires land, but not all land is suited to agriculture. In fact, natural land seldom is capable of more than the most primitive of agricultural uses such as grazing or the collection of wild grains or hay. To prepare it for more intensive uses requires the investment of labor and money to clear, drain, fence, survey, or otherwise improve or allot it for tillage. Therefore, land as a factor in production is not, like the air, a free gift of nature. It must be won, and hence it has value.

Since agricultural land must be produced through the investment of capital and labor, it follows that much of the land of the world is incapable of becoming economically agricultural, since it could never be made sufficiently productive to pay adequate returns on the investment. Handicaps of one kind or another inherent in its conditions of climate, soil, or surface configuration impose limits on its utility. It was the purpose of Part One of this book to state in some detail the complex of natural elements some of which govern the quality of land, and there is no need to review them here. However, there are factors other than those of physical nature that are concerned with the value of land. Included among these are economic location, *i.e.*, an advantageous location with respect to other lands or to centers of population. Because the inherently fertile lands of the earth cannot be moved to advantageous locations, provided they do not have them, some that are inherently less productive have higher sale values because of better situation. A supply of good agricultural land is, however, one of the critical elements in the environmental complexes with which the regions of the world are endowed.

Significant Agricultural Elements and Their Classification

The distinguishable elements of culture that are associated with agricultural production are both numerous and varied. Only a few of them are noted here, and principally those which have material form and are observable. The following paragraphs comment upon those which are considered particularly significant as giving character to the various types of agriculture in the world and in making it possible to distinguish one type from another. The farm population, their houses and farmstead arrangements and structures, have been discussed previously.

793. Percentage of the Total Land Area of a Region Agriculturally Utilized. Certainly one of the most fundamental geographic items concerning any region has to do with the percentage of its area that is agriculturally productive, *i.e.*, is utilized for the *raising of crops*

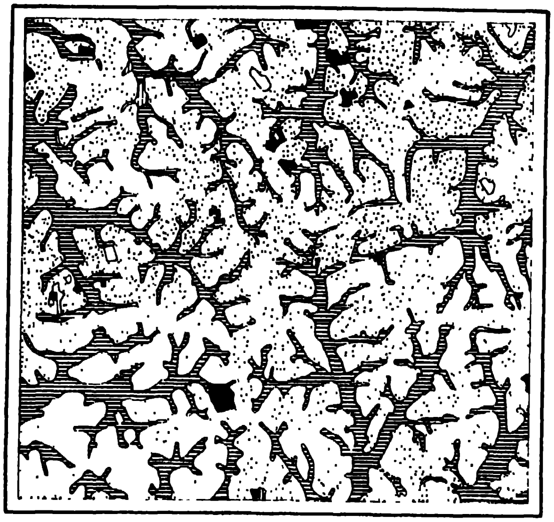

Fig. 413. Pattern of agricultural land in humid, southwestern Ceylon. Rice occupies the river floodplains, and coconut groves the interfluves. (*Ceylon Survey, Avisawella sheet.*)

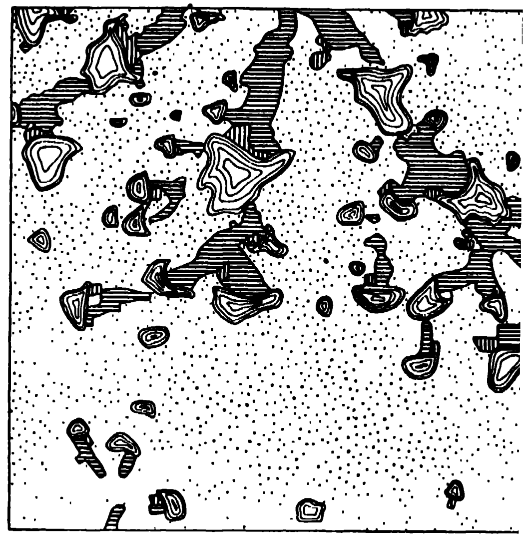

Fig. 414. Pattern of cropped land in northern Ceylon where tank irrigation is practiced. (*Ceylon Survey, Medawachchiya sheet.*)

or the *pasturing of animals*. For the world as a whole there is a marked concentration of farmed land in the humid sections of the middle latitudes. Throughout the polar lands and the deserts the land is only meagerly utilized, mainly because of obvious climatic handicaps. Large parts of the wet tropics also have only sparse agricultural development, although the reasons for this are more complicated and less obvious. But even in the humid sections of the middle latitudes, where the world's agricultural lands are concentrated, there are wide variations in the percentages that are in farms. This comes about chiefly as a result of differences in climate, surface configuration, soil quality, drainage condition, location with respect to the great industrial markets of the world, and the intensity of the need for land. The last named depends in part upon the history of settlement, the cultural inheritance, and the standard of living of the inhabitants.

In the United States, where about 60 per cent of the total land area is held in farms, the percentage varies locally from less than 10, in parts of the sandy and swampy Coastal Plain, the ice-scoured crystalline rocks of the northeast, and the arid West, to more than 90 per cent in the level and fertile plains of the central Mississippi Valley region. In Japan, largely because of the rugged nature of its land surface, less than 20 per cent of the country is agriculturally productive. In Norway, where rugged surface combines with severe ice scour, the comparable figure is 5 per cent or less.

794. Distributional Pattern of Agricultural Land. Not only the amount, but also the distributional aspect of farm land is geographically significant (Figs. 413 and 414). In the Laurentian Upland of Canada, for example, the distributional pattern of cultivated land is an exceedingly patchy and fragmented one, concentration being upon isolated areas of glacial till and glaciofluvial plains separated from each other by barren hill lands, swamps, and forests. This is quite in contrast with the distribution pattern typical of much of the Mississippi Valley, where deep soils and the general absence of rugged terrain permits farms to occupy almost the entire surface in

contiguous blocks as far as the eye can reach. That is not true of all parts of the United States or even of much of the highly tilled plains of western Europe or of many other parts of the world where there are interruptions to the continuity of farm lands. Areas of unproductive sand or swamplands and hill lands in forest, owned by governmental or corporate bodies, separate certain tracts of farm land from each other, create patterns of great irregularity, and provide the nonagricultural spots in the utilization fabric.

795. Plowed or Cropped Land and Permanent Pasture. Agricultural lands in general yield valuable products of several different classes such as crops, pasture, wood, and others. Undoubtedly crop land and pasture land occupy the larger areas and are much the most important. It should be emphasized that, in creating a picture of the use of farm land within a region, two elements are significant with respect to each of these uses of land: (*a*) the quantity aspect, expressed in terms of percentage of the whole area so utilized, and (*b*) the distribution pattern of each type of land use. Unfortunately the information available from statistical sources and from field surveys is not uniformly adequate for the creation of such a picture, and if it were the details of quantity and distribution would far exceed the limits of the present space. It is possible, therefore, to present only the most general of pictures in terms of contrast and for large areas.

In the United States, where nearly 60 per cent of the total national area is in farms and ranches, only about 19 per cent of the total area, or 31 per cent of the farm-land area, is in tilled crops, and this is very unequally distributed. In arid parts of the western states, for example, there are many counties in which no more than a small fraction of 1 per cent of the total area is under tillage, while in certain sections of the Corn Belt nearly all the farm land and more than three-fourths of the entire land area is tilled (Fig. 415). In the United States as a whole, more than two-thirds of the

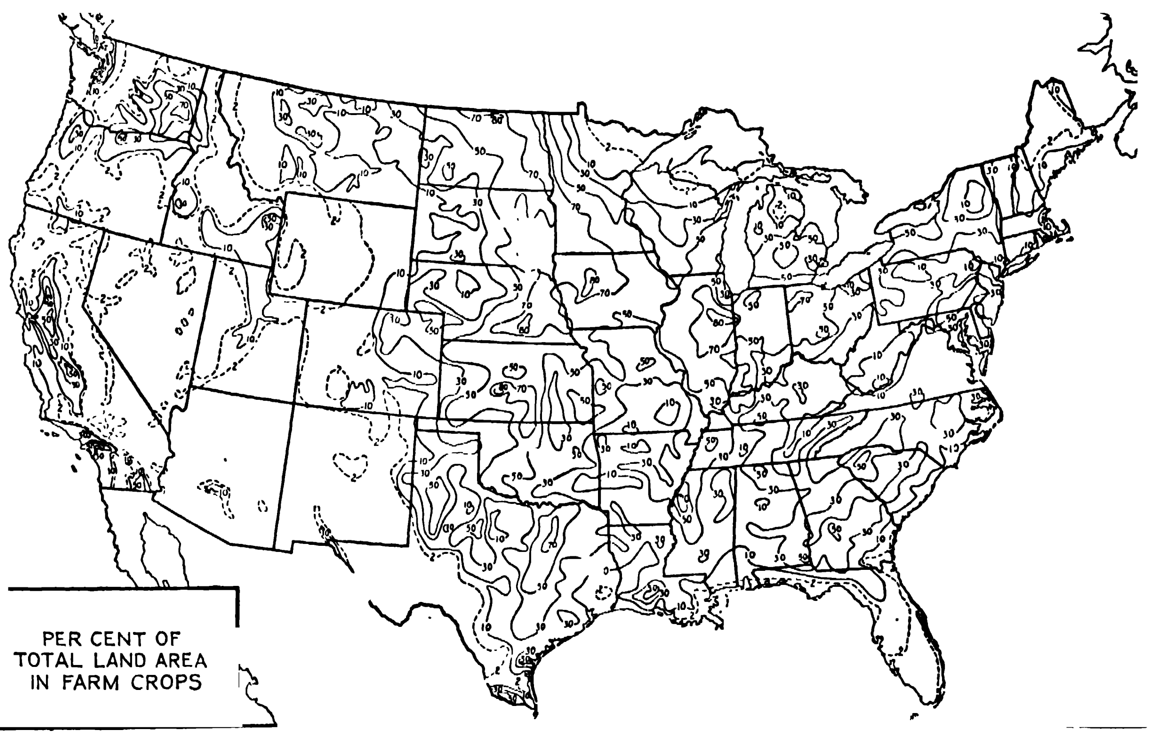

Fig. 415. In three widely separated parts of the United States the proportion of the total land area, by counties, that is used for tilled crops is less than 2 per cent, and only in the Corn Belt does it exceed 75 per cent.

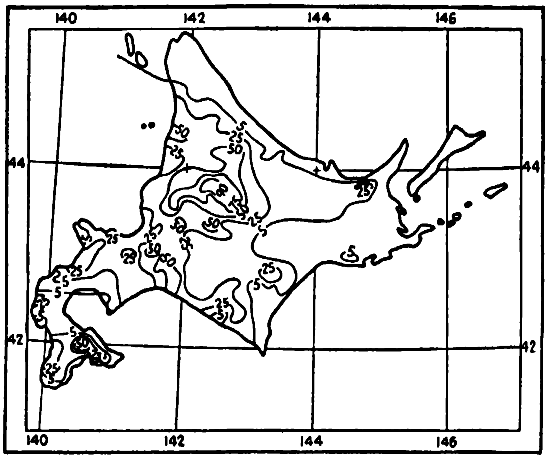

Fig. 416. Per cent of the total cultivated area that is planted to rice in Hokkaido, the northern island of Japan.

farm lands are in permanent pastures, woodlands, idle or fallow lands, and other uses. The area of land potentially available for crops is about 25 per cent larger than that actually used, but much of the additional area is land on which crops have failed or is fallow land or pasture land which could be plowed. In addition there are large areas of grazing lands on the public domain, in the national forests and on other lands not owned by farmers. In Japan and China proper, on the other hand, tilled land occupies a much more significant place in the land-use system. The human populations of these countries are dense, and most of the tillable lands are used to produce food for direct human consumption, the animal industries are only meagerly developed, and grazing lands do not occupy a significant area. In New Zealand the situation is quite the opposite. It is a newly settled country with a small population, a large livestock-grazing industry, and a small requirement for the kinds of food crops that must be raised at home. Consequently, a large area of potentially tillable land is devoted to pasture, and only about 3 per cent of the total area of the country is under the plow.

796. The Proportions of the Plowed Land in Various Crops. A further refinement in the analysis of the uses of farm land, following the distinction of plowed land from that in other uses, would show the subdivision of the plowed land into the kinds and amounts of the various crops raised (Fig. 416). In the United States, for example, of the farm-land area cropped, approximately 25 per cent is planted to corn, 21 per cent to hay, 19 per cent to wheat, 5 per cent to cotton, 12 per cent to oats, 2 per cent to sorghums, and 3 per cent to barley. These seven crops occupy about 87 per cent of the acreage in all crops. But within the country are regions of agricultural specialization, the percentages for which are greatly different from the average figures for the country as a whole. For example, one county in North Dakota, representative of the spring wheat belt, has 40 per cent of its cropped land in wheat, about 12 per cent in hay and forage crops, 19 per cent in barley, 13 per cent in oats, and only 5 per cent in corn. A county in the Iowa Corn Belt, on the other hand, has 52 per cent of its crop area in corn, 18 per cent in oats, 12 per cent in hay, 10 per cent in barley, and only 2 per cent in wheat. These percentages show remarkable contrasts in crop emphasis and differences between the agricultural systems of the two regions, although the percentages of the total areas in harvested crops in the two areas is not greatly different.

797. The Amount Produced per Unit Area. Although areal spread or acreage certainly is the most fundamental geographic fact concerning agricultural land utilization, the crop yield per unit area is important supplementary information. It is an indication of the quality of the land and of the intensity of the farming practices as well. An acre of corn in terms of space occupied is identical in Iowa or Georgia, and yet the average per acre yield of corn in bushels is about 50 in the first state and only 10 in the second. This is in large part an expression of difference in the fertility of the dark prairie soils of Iowa and the lateritic red and yellow soils of Georgia. An average acre of rice land in Japan produces approximately 70 bushels of rice; in the United States, 48 bushels; and in the Philippine Islands, only about 22 bushels. The rice lands of the United States have, in the main, new dark prairie soils which certainly are not inferior to the much

cropped alluvial lands of Japan. Their lower yields are indicative of much more extensive farming methods, where yield is sacrificed to save on cost of production, whereas in Japan the soils are heavily fertilized and vast amounts of human labor are expended to bring the yield of rice up to a high level. In the Philippine Islands primitive methods result in lower average yields than those obtained by extensive farming on good lands in the United States.

798. Cropping Systems and Practices; Seasonal Landscapes. Depending largely upon climatic conditions, the seasons of planting and harvesting vary greatly from one part of the earth to another. In the constantly wet tropics, where there is no generally dormant season for vegetation by reason of a deficiency of either heat or precipitation, definite seasons for planting or harvesting are not conspicuous. Seeds may be put into the soil at any time with assurance that conditions are satisfactory for their growth and maturing. In the savanna lands, on the other hand, where a dormant season is imposed by the drought of the low-sun period, there is a definite seasonal rhythm to agricultural practices. Except where irrigation is developed, crops are normally planted at the beginning of the rains and harvested during the dry season. Fields commonly lie fallow during the period of low sun. Throughout the middle latitudes a seasonal rhythm of agricultural operations is usually imposed by a period of cold, although in some parts a drought season may have the same effect. But over the middle latitudes as a whole, winter, or the period of low sun, is the dormant season for agriculture, whereas spring is the season of planting, summer of growth, and autumn of harvesting. This characteristic cycle is so well recognized that it has impressed itself upon the customs, habits, recreations, and literature of the inhabitants.

There are important departures from the previously noted cycle. On the tropical margins of the middle latitudes the mild winters permit some crops to flourish throughout the cool season. Thus the American Gulf Coast region, southern California, and Mediterranean Africa are important producers of winter fruits and vegetables for the markets farther north. Although oranges are picked throughout the year, the principal season is winter, when other fruits are scarce and expensive. In the dry-summer subtropical, or Mediterranean, regions where the periods of maximum heat and maximum rainfall do not coincide, the cereal crops commonly are planted in the fall at the beginning of the rains and harvested in late spring. In those regions of mild Mediterranean climate, grains grow more or less continuously throughout the winter. Even in the warm-summer phase of the humid continental climates, hardy cereals such as wheat and rye are fall-sown, although growth practically ceases during the winter. Most of the wheat grown in, and to the south of, the American Corn Belt, as well as that of western and central Europe, is designated as winter wheat, meaning that it is sown in the autumn. In the higher middle latitudes (subarctic, and humid continental climates with cool summers), however, the winters are severe, and practically all crops are spring-sown, the fields being free of crops in winter.

799. *Multiple Cropping and Interculture.* It is customary in the United States to raise only one crop in a field at a time and to plant a field only once during the course of a year. After the single crop has been harvested, the field is then usually allowed to lie fallow until the next year's planting season arrives. But in countries of dense population and restricted agricultural land areas, and especially in those where the growing season is relatively long, such practices as *multiple cropping* and *interculture* are common. By multiple cropping is meant the practice of replanting a field to a second crop after the first has been harvested, so that two and occasionally three harvests are obtained from the same land during the course of a year. In Japan, for example, 40 to 50 per cent of the rice fields are replanted in autumn to unirrigated crops such as wheat or barley.

Interculture is a kind of simultaneous rotation of crops in alternate rows, by which two or more different crops, planted at different times, are grown together in the same field.

By this "close dovetailing rotation of crops in point of time, space, and labor" two or three harvests may be obtained in one year. In Japan summer vegetables frequently are intercultured. Four-fifths of the Italian vineyard acreage represents mixed crops, the rows of grapes being alternated with fruit trees which serve as their supports, with grain and vegetables frequently planted between the vine rows. Hay or grain crops are sometimes grown in American orchards.

800. Livestock Production as a Phase of Agriculture. Two large divisions of specialized agriculture may be recognized: (*a*) the growing of crops and (*b*) the raising of animals, although frequently the two types of economy are combined, even on the same farm. Certain crops, to be sure, such as rice, wheat, flax, cotton, and tobacco, are converted directly into forms useful to human beings. Others like corn, oats, hay, and mulberry are principally used as feed for domestic animals, which in turn furnish products or services for human use. However, many of the world's economically important domestic animals are grazers, and certain types of animal industry are found in regions where natural grass pastures, hay, and forage crops are abundant, whereas others are more sharply restricted to areas producing grain and other concentrated feeds. Since the earliest times the natural grasslands have been regions of extensive livestock production.

801. Uses of Animals and Animal Products. Under modern farming conditions the raising of livestock is done in such a variety of ways, and for such diverse purposes, that classification is not easy. Most animals, however, serve one or more of three general uses: (*a*) as sources of food, such as meat, milk, eggs, or honey; (*b*) as sources of industrial products, such as fibers (wool, hair, silk) or leather (hides)· (*c*) as beasts of draft or burden. The kinds and quantity of animal products emanating from a region are important geographic data.

802. Systems of Livestock Production. The systems of economy under which livestock are raised are several. At one extreme is the *nomadic herding* practiced by the tribal peoples of dry Africa, inner Asia, and the Asiatic tundra. A somewhat more advanced stage in animal industry is represented by *livestock ranching*, a commercial form of livestock grazing such as that practiced in western United States, the steppe lands of South Africa, or the dry interior grasslands and savannas of South America. A still more intensive stage of animal raising is to be found in those humid lands of general agriculture where there is an abundance of good pasture and, in addition, a plentiful supply of grain and forage crops for feeding. In part the animals forage for their food, even though their movements are limited by fences, but heavy feeding from the crops produced on the farm is also practiced. This type of commercial *livestock farming* is well developed in western and central Europe, the American Corn Belt, and parts of the Argentine Pampa.

803. Number of Livestock per Unit of Area. Primary in determining the importance of any region in animal production, no matter of what kind, is information relative to the number of animals per unit of area (square mile, acre, or other unit). To obtain this in comparable terms it is necessary to reduce the various kinds of animals to a common denominator, which may be called a *livestock unit*. This may be considered to be the equivalent of one horse, one mule, one cow, seven sheep, seven goats, or five swine. On this basis one may compare the relative numbers of livestock per square mile in different regions.

804. Livestock Units in Relation to Area of Cropped Land. Important as the above data are, however, they are not sufficient to give a clear notion of the importance of livestock in the regional economy. As an illustration, Natrona County in east central Wyoming and Fond du Lac County in southeastern Wisconsin have, respectively, about 14 and 140 livestock units per square mile. On the basis of these quantity data alone, one might conclude that Fond du Lac County is highly specialized in livestock production, and that Natrona County is not. But this is not the case, since relatively the Wyoming county is more dependent upon livestock than is the Wisconsin

ally smaller, 85 per cent of the holdings in France containing less than 25 acres. In Switzerland they average about 20 acres. Japan, representing one of the world's most densely populated rural areas, far surpasses most of Europe in the smallness of farms, the average size being only 2.6 acres, or about half an acre for each member of the farm family.

807. Shape and Composition. A large part of the farms in the United States are roughly rectangular in shape and are composed of a single contiguous block of land. The farm is further divided into several individual fields of a variety of shapes and sizes but with a tendency toward rectangularity, especially where the land is not too rough (Fig. 418). The prevalence of right angles in the landholding pattern of the United States is largely the result of the original land surveys by which most of the country, excepting the eastern and southern states, was subdivided by north-south and east-west lines coinciding with meridians and parallels (see Appendix C for a discussion of the American system of rectangular land survey). The section, 1 mile on a side, became the basic land-subdivision unit. Usually the American farms, as well as the individual fields, are enclosed by fences, although this is not always the case. In the flat lands of the Argentine Pampa rectangular land subdivision prevails also.

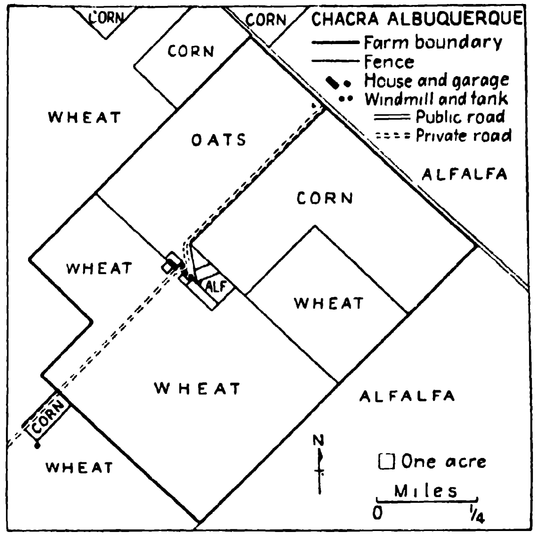

Fig. 419. Arrangement of fields and farmstead on an Argentine farm of 554 acres. (*Map by Robert S. Platt.*)

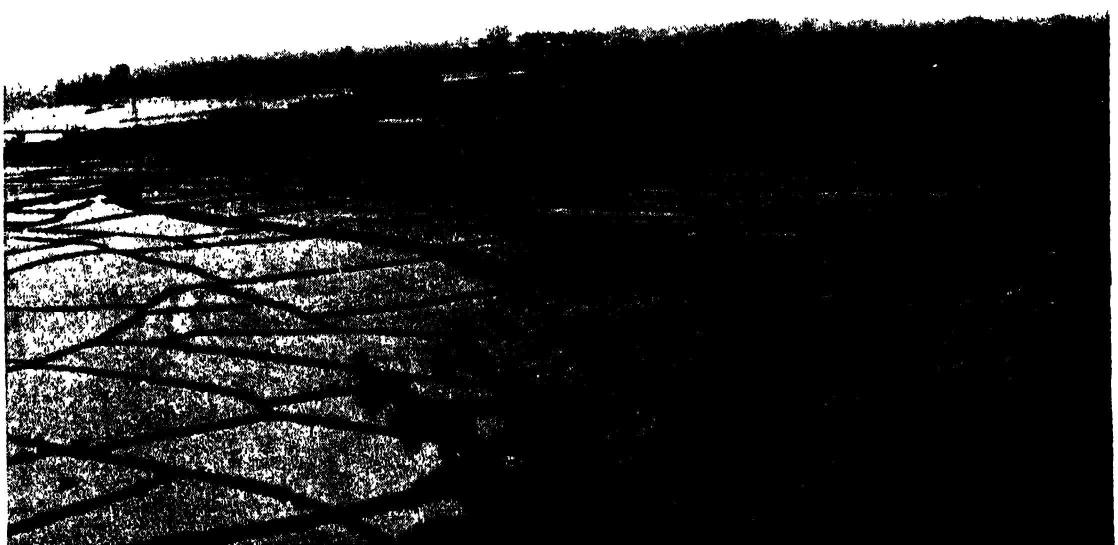

Fig. 420. Pattern of irrigated rice fields on a Japanese plain. The individual fields are only a fraction of an acre in area.

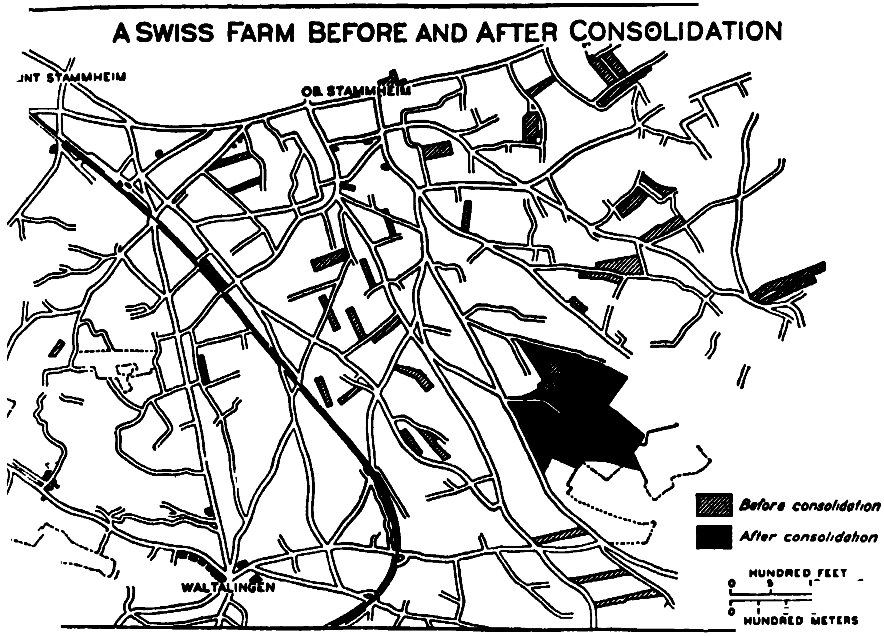

Fig. 421. In many parts of the world the farm is not in one contiguous plot, but is composed of several isolated parcels. The average Swiss farm has a total area of 21 acres in 14 separate plots. (*Courtesy of U.S. Department of Agriculture.*)

It is not, however, systematically oriented with respect to compass directions (Fig. 419).

Quite in contrast with the foregoing picture are the farms of many European countries or those of the Orient. The Japanese or Chinese farm, instead of being one contiguous plot, usually is composed of several small, unfenced parcels of land of different sizes and shapes (Fig. 420). The parcels are scattered in various directions and distances about the rural village where the farmer dwells. For North China, where farms average 4 to 7 acres in size, there is an average of about six separate plots per farm. The plots average not far from an acre in size, and their average distance from the farmstead is slightly over half a mile. This open-field system with noncontiguous plots is also typical of France and other parts of continental Europe (Fig. 421). The representative Swiss farm, with a total area of about 21 acres, is composed on the average of over 14 unfenced parcels.

808. Regional Classification. The foregoing paragraphs of this chapter have attempted to outline the more significant elements in the agricultural complex of a region. The definition of an agricultural region would therefore rest upon the ability to recognize some distinctive association of these major elements. Unfortunately for the ease and clarity with which such regions may be delimited, the elements are many, some are capable of census enumeration or statistical computation, and others are not. Moreover, some parts of the world are covered by adequate and detailed agricultural census enumerations. Others have but general enumerations or none at all. From this it may be concluded that, although agricultural regions may be delimited for some parts of the world with fair precision, it is not possible for the world as a whole. Regions for the world as a whole must be general, and for some of them many of the desirable facts are entirely lacking. For none of them is it possible to proceed systematically through the entire list of even the known elements, since the present purpose and space does not permit so great detail. Moreover, a map to accompany such a world subdivision as is here proposed must be at a small scale and therefore general. The regional types outlined on this map may appear simple but are in fact mere generalizations of complex associations. Within each of the areas mapped as units are many

variations which could be brought out only by means of a much more thorough analysis than the present purpose warrants.

The following classification and the map of agricultural regions (Plate VIII) are therefore limited to a subdivision of the world into little more than a dozen agricultural types. In this it is in accord with the general classifications of climates, landforms, soils, etc., that have been employed in this book. For the basis of this agricultural classification the authors acknowledge great indebtedness to Profs. Derwent Whittlesey and W. D. Jones,[1] Richard Hartshorne and Samuel N. Dicken,[2] and to Dr. O. E. Baker[3] and others whose writings have contributed the classifications of world agriculture most applicable to the present point of view. In the classification by Whittlesey the regional distinctions rest primarily upon a brief list of features that have recognized functions and have been noticed either in the foregoing part of this chapter or in earlier chapters of Part Two. They are

1. The crop and livestock association.
2. The methods used to grow the crops and produce the stock.
3. The intensity of application to the land of labor, capital, and organization, and the output of products that results.
4. The disposal of the products for consumption (*i.e.*, whether used for subsistence on the farm, fed to livestock, or sold off for cash or other goods).
5. The ensemble of structures used to house and facilitate the farming operations.

Major Agricultural Regions

809. Types of Regions. Even the most casual survey of world agriculture shows strongly contrasting groups of regions: (*a*) those in which the major emphasis is upon the raising of animals, (*b*) those in which crop production is dominant, and (*c*) those in which these basic functions share about equally in the attention of the farmer. Each of these, however, is capable of further subdivision, and the various resulting types are of different degrees of economic intensity, some requiring a high concentration of labor, capital, and organization upon the land, and others requiring but little. In the following types it is not possible to say precisely in all cases which is a more and which is a less intensive form of agriculture. However, the general arrangement is intended to present first the most primitive and least intensive forms of agricultural and pastoral enterprise and to reserve until last those of more advanced and intensive nature.

810. Nomadic Herding Regions. Nomadic herding is a primitive form of livestock industry. Those who live by means of it have no fixed habitations, but migrate with their flocks and herds in search of water and forage. They are but a step removed from the hunting stage of human economy. The animals kept by nomadic herdsmen include most of the domesticated herbivorous species such as horses, cattle, camels, sheep, goats, and reindeer. These supply their owners with most of their wants in foods and raw materials: meat, milk, wool, hair, skins, and utensils. They supply transportation also to those who live in sparsely peopled districts. This is a subsistence type of animal raising.

Nomadic herding once was widespread in Eurasia and Africa, where it evolved with primitive civilizations, but it has suffered encroachment there by higher forms of land use. This encroachment still is in progress in Asia, where Chinese farmers slowly crowd the nomads from the more humid margins of Inner Mongolia In recent years also the agricultural revolution in the Soviet Union has forced some of the inhabitants of the Siberian steppes to settle upon the land over which they and their ancestors have roamed for centuries. On the other hand, pastoral nomadism was not

[1] Derwent Whittlesey. Major Agricultural Regions of the Earth. *Ann. Assoc. Amer. Geographers*, Vol. 26, pp. 199–240 and plate, 1936.

[2] Richard Hartshorne and Samuel N. Dicken. "Syllabus for the Introductory Course in Economic Geography." Pp. 26–54 and plate. Edwards Brothers, Inc., Ann Arbor, Mich., 1939.

[3] O. E. Baker. Agricultural Regions of North America. *Econ. Geog.*, Vols. II to IX, 1926 to 1933.

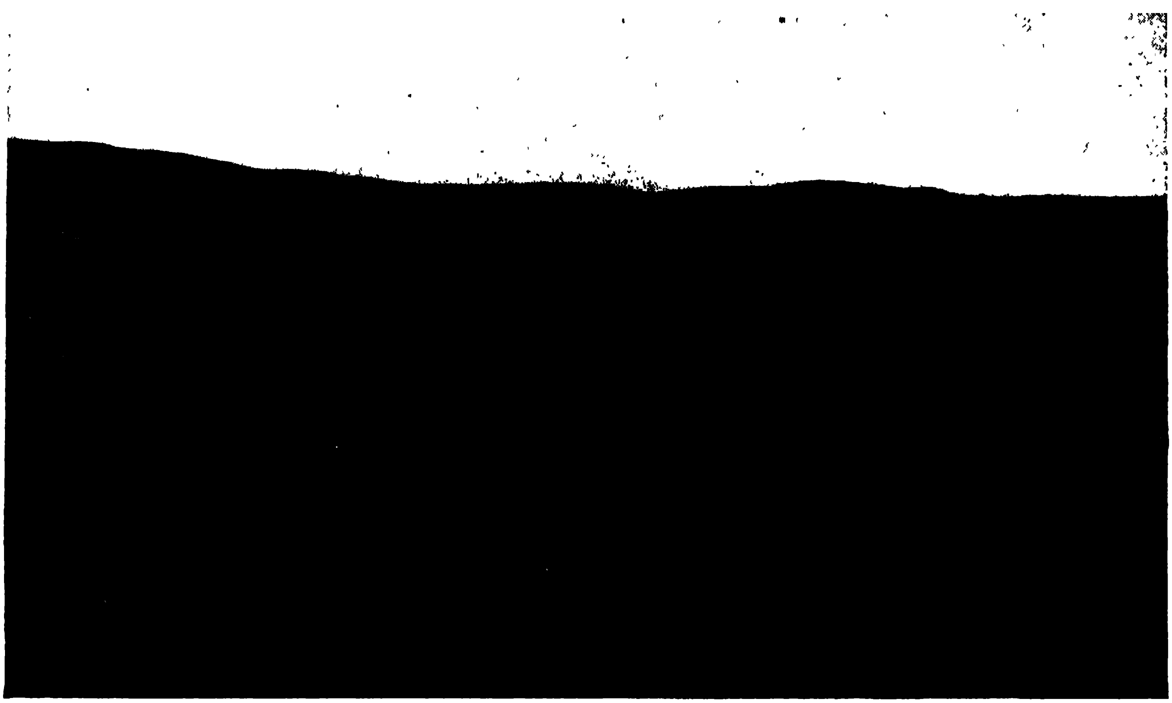

Fig. 422. Slender fences of barbed wire divide western cattle ranches into large fields.

native to the American continents or Australia. In those continents the aboriginal inhabitants were either hunters of wild animals or tillers of the soil, having few domestic animals, and the later European immigrants had already developed beyond the nomadic stage. Only after the introduction of horses to the New World did the American Indians become, for a brief time, nomadic herdsman, owning bands of ponies but little other stock. More recently the introduction of reindeer among the Eskimos of western Alaska and northwestern Canada has established a region of nomadic herding which may prove to be permanent.

The world regions that are characterized by nomadic herding (Plate VIII) are mainly those which are dry, either actually or physiologically: steppe lands, desert margins, and tundra. The severely dry deserts of the Old World produce little of forage and have few watering places. They are unable to support even sparse nomadic populations, although bordering tribes make temporary incursions upon them to utilize the short-lived forage that springs up following rains. The largest remaining regions of nomadic herding are those of central Asia and northern Africa.

811. Livestock Ranching. The steppe lands and desert margins of the Americas and Australia are regions of livestock grazing also, but the economic nature of the industry there is different from nomadic herding. In the United States it is called livestock ranching, and that name may be applied to it generally. It is, from one viewpoint, a retrograde form of settled agriculture. Farmers of European origin, accustomed to tilling the soil, occupied dry lands in the new continents and took up livestock grazing because aridity did not permit of satisfactory tillage. Although they adopted the means of existence of the pastoralist, they did not adopt the nomad's manner of life. Instead they retained the tradition of a settled habitation, the ranch house, and the idea of private ownership of the grazing lands, which were protected by patrol of their borders and by the ultimate building of fences to separate properties or even to divide individual holdings into great pasture fields (Figs. 422 and 417).

Livestock ranching, unlike pastoral nomad-

ism, is a commercial form of land use. The livestock products are used by the ranchman to a limited extent only. Instead they are sold on local or world markets for a cash return, with which the ranchman buys his requirements. It is also a more intensive form of agriculture than pastoral nomadism, attention being given to the selection and breeding of stock, the artificial provision of water through wells, and even some tillage of the soil where a supply of irrigation water permits. Thus supplementary feed crops may be grown and some food for the ranch family. Although the ranch animals ordinarily are confined within the ranch limits, this is not always the case. In the North American cordilleran region, for example, cattle and sheep are driven from winter pastures on the lowland ranches to summer grazing on mountain pastures that are not a part of the ranch but are hired from governmental or other owners. This kind of seasonal migration of livestock is very ancient and belongs also to pastoral nomadism in the Old World and to other types of livestock management as well. It is called *transhumance*.

Within the several livestock ranching areas shown in Plate VIII are numerous modifications of the general type. The system of management and the kinds of livestock raised in the middle-latitude steppes of the United States and Argentina, for example, are not exactly like those of the tropical grasslands of Brazil or northern Australia. On the humid borders of the North American high plains, where good railway transportation permits of ready access to a large market, the ranches are smaller and the livestock industry more closely associated with crop tillage than in distant northern Australia. In the latter region in fact are some of the largest ranches, or "cattle stations," in the world, several of which, according to Conigrave, reach an area of 5,000 square miles each, and at least one covers more than 12,000 square miles, or nearly as much as the states of Connecticut and Massachusetts combined. On the desert margins everywhere the capacity of the land to support livestock is limited by the sparsity of the forage, and the number of livestock units per square mile is small. In the good grasslands of western Nebraska, for example, 10 acres may be sufficient to support one animal unit, but in the drier lands of central Wyoming it may require 25 to 50 acres, and in the desert lands of Arizona and Nevada more than 75 acres. Beyond a variable aridity limit, the area required to support livestock sufficient to maintain a commercial ranch unit becomes so great that it is no longer profitable to utilize it for ranching.

812. Rudimentary Cultivation. In the tropical forest regions and upon their savanna and highland margins are vast areas of land which are used for agriculture in a rudimentary way. In the lowland areas abundant heat and moisture have given rise to a luxuriant natural vegetation, but they also promote luxuriant weeds once the original vegetation is cleared away. These mainly are the regions of the tropical red soils whose store of fertility is quickly exhausted under continuous cultivation without skillful management. This the primitive farmer cannot provide, and hence he is forced to adopt a system of cultivation that requires new lands for temporary exploitation. The inhabitants of some of these regions live under tribal organization, and in their agricultural adaptations to their surroundings they act in tribal groups.

Among the various rudimentary systems of culture two general types may be recognized. The first involves the clearing of fields in the forest, their tillage for one or more years in simple subsistence crops, such as manioc, until weeds or soil exhaustion through depletion of organic material or accelerated erosion forces their abandonment. This continues until all the available field sites convenient to the settlement have been used. Then the entire group moves to a new site and establishes a new village settlement in a locality far removed. The old site quickly reverts to forest, and after some decades it may again be cleared as new land in a process of slow rotation during which the soil recovers some of its elements of fertility and the troublesome weeds have been crowded out by forest growth. This system is sometimes called *shifting cultivation*. The second type is slightly more ad-

vanced and commonly is found in tropical forest localities where the population has become somewhat more dense and especially among such groups as have some contact with the world outside and some sale for the products of their cultivation. In this system the fields are cleared of their original cover, cultivated, and abandoned as before, but the village seldom is moved. This system requires a more frequent reusing of abandoned fields and a considerable intensification of the agricultural practices, the labor for which is provided by the larger population. Tree crops, such as palm nuts and cacao, are sometimes planted in the abandoned clearings, income is derived from the land thus planted, and its reversion to forest is delayed or prevented. This is a rudimentary form of settled or *sedentary* agriculture.

The tribal farmers who till by these methods live in huts that are built of local materials. They have few livestock other than poultry and but little understanding of land fertilization or other advanced agricultural practices. They are able to clear new land by means of ax and fire, but their methods are not intensive. They till the land with a sharpened stick or a hoe, tools that are inadequate for the repression of a vigorous growth of weeds. The larger part of the regions that are characterized by rudimentary tropical tillage are exceedingly remote from routes of transportation, and the products of their cultivation are for subsistence only. A smaller part only produces some crops for sale, and mainly they are the tree crops. This may be, however, a type of intensification that indicates a general encroachment upon the regions of primitive tillage. The larger of these regions as outlined in Plate VIII, it will be seen, are mainly within the area of the tropical rainforests. Only in parts of Africa, where infectious diseases prevent the keeping of horses or other work animals, does the rudimentary type of tropical tillage extend much beyond the forest and scrubland border.

A related form of rudimentary agriculture is practiced by the highland Indians of Central America and the Andean regions. They clear and till small fields on the mountain and valley slopes, and these, when the soils are depleted or badly eroded, are allowed to revert to pasture or bushwood. However, the settlements of the cultivators remain fixed or are moved only at long intervals when no more land is available within reasonable distance. Although these agricultural practices are rudimentary in form and similar in type to those noted above, the crops are different from those of the adjacent lowlands owing to the lower temperatures of mountain climate.

813. Intensive Subsistence Cultivation. In parts of eastern and southern Asia are ancient centers of civilization in which agricultural skills and implements long ago made it possible to support many more people per unit of area than is possible under rudimentary cultivation. The further growth of population required ever-increasing intensity in the use of agricultural resources and gave rise to distinctive systems of tillage. In the main they are of the subsistence type, only a small part of the farm produce being sold away from the locality of its production. Most of the readily tillable land is used, and additional areas are created at great labor through land drainage and the terracing of hillsides. Only the steepest slopes and the least productive soils remain in woodlands or pastures, but in some hilly districts woodlands occupy a significant part of the total area, nearly two-thirds in Japan, for example. The animal industries are only moderately developed, since the major part of the land, and especially the cropland, is required to produce cereals and vegetables for direct human consumption. In this respect, however, parts of the Asiatic region differ because of contrasts in religious tolerance. In China and Japan there are relatively few cattle and sheep but many swine and poultry that can be supported from agricultural and household wastes Even ponds and streams are made to yield their maximum of food through the cultivation of fish and waterfowl. In India, on the other hand, religious custom forbids the use of flesh, and there are no swine or other animals used for food. There are, however, many cattle, water buffalo, and goats. These are used to pull the plows much more extensively than in

China, where hand labor predominates, or as sources of milk and other animal products.

There is another significant agricultural contrast between parts of the general region of intensive subsistence cultivation. In the more rainy tropical and subtropical portions the cropping system is dominated by the growing of rice, and all other cultivated crops take places subordinate to this most productive of cereal grains. Rice occupies the irrigable deltas, floodplains, coastal lowlands, and terraces. Other grains occupy unirrigated lands or replace rice on the irrigated land in the cooler and drier season, after rice harvest. In the more tropical portions, where the growing season is long, multiple cropping enables two crops of rice to be harvested, which, together with beans, vegetables, and other crops, provides food for large numbers of people. These live in innumerable farm villages and till their tiny fields with endless patience and hard labor (Fig. 406), but seldom do they achieve more than a bare existence. In contrast with these rice districts are the more northerly portions and interior highlands of China and Japan and the dry interior of India, where the summers are either too short or there is not sufficient irrigation water for the cultivation of rice. There various other cereal grains, especially wheat, corn, the grain sorghums, and millets, take its place. They are associated with beans, vegetables, and many other crops, such as cotton. The major areas of rice dominance are distinguished in the regional map (Plate VIII). In addition to the major areas of intensive subsistence cultivation outlined on the map there are others too small to be shown at that scale. Mainly they are in the Old World, and most of them are the densely peopled oases or irrigation regions. Of these the oasis of the Nile Valley in Egypt is a conspicuous example large enough to be shown on the map.

814. Commercial Plantation Cultivation. Common in the tropics, and in some areas closely associated with the rudimentary and subsistence forms of tillage, is another type of agriculture of very different character. Its purpose is the production of a single crop or limited group of crops for cash sale. They are produced on an extensive scale by efficient methods and in standard forms. The products most susceptible to this type of management are certain world staples that are required in large quantity, mainly in the industrial regions of the Northern Hemisphere. Such are bananas, tea, coconut oil, rubber, and certain tropical fibers. The choice of plantation site is made with reference to its ability to produce one of these commodities in large quantity and of superior quality, and hardly any other crops are grown. The capital for plantation development, the skilled personnel for its management, the machinery for its operation, fertilizers for the crop, part of the food for the laborers, and sometimes even the laborers themselves are brought from outside the locality, and some of them from the farthest parts of the earth. On many plantations the laborers live in village settlements at the plantation center and work in gangs under supervision. This is notably true of rubber and tea plantations. Some kinds of plantation crops require also a preliminary processing or elementary manufacture before they are shipped to their foreign destinations, and the plantation center is distinguished by an establishment for that purpose. Such are the large sugar mills, coconut-oil mills, and the factories required for curing and packing the freshly gathered tea leaves, rubber latex, and other crude plantation crops.

Like other agricultural staples, the products of plantation agriculture suffer from competition on the world market. There are few crops so restricted by nature that they cannot be raised in more than one region. Moreover, the great plantation establishments, once they have created a large market and have demonstrated efficient methods of production, begin to find competitors in the small farmers of their respective regions. Some crops such as sugar and cotton once were produced, and still are to some extent, under plantation systems of management but now are grown even more largely by a modified plantation system or by independent small farmers. The United States cotton region is an outstanding example of this change. The abolition of slavery, the breaking up of the great plantations, the lack of necessity for any expensive equipment in cotton growing, and the

westward expansion of cotton into the subhumid districts have almost extinguished the true plantation system that once prevailed. Similar if less extensive changes have taken place in the Cuban sugar industry, the Brazilian coffee industry, and others. In fact, small commercial farms prevail over considerable parts of these regions, and an almost complete transition is to be found between the highly centralized plantation on the one hand and the small cash-product farm on the other. Those plantations tend to resist longest the effects of private competition whose products are of such a nature that they require some kind of special handling or expensive processing or standardizing between the field and the shipping point, things the small farmer is unable to provide.

Some attempt has been made in Plate VIII to distinguish between the areas of highly centralized plantation cultivation and those transitional forms noted above. The simple distinction provided does not do justice to the complication of the facts. Several of the areas are so small as to require special symbols to make them stand out, and none of them is marked in such a way as to distinguish the special product for which each locality is noted. Added detail regarding these, and the reasons for their locations, is a part of the subject matter of economic geography.

815. Mediterranean Agriculture. Although Mediterranean agriculture is not distinguished on quite the same basis as the other types noted here, it is an ancient association of cultural and natural features well recognized by geographers. The unique combination of dry subtropical climatic features together with hilly land or bordering plateau surface is, in each region of its occurrence, associated with a distinctive combination of crops and livestock industries, although the relative importance of the several component cultural elements is not everywhere the same. Cereal grains, especially wheat, grow during the mild, moist winter and mature with the coming of the dry summer. Certain other crops that are sensitive to low temperatures are native to the regions of Mediterranean climate and find there the freedom from severe frost necessary to their growth. Such are the olive tree and the grapevine. Xerophytic character or deep roots that seek underground water enable them to endure the summer aridity and produce their fruits at the end of the dry season. Still other crops of humid tropical or subtropical origin have been introduced into the Mediterranean regions by man. They find there the mild winters they require, but they are not naturally adapted to the summer aridity and are able to survive only where they are supplied with water by irrigation. The citrus fruits are the outstanding example of this group of crops (Fig. 193). However, where irrigation water is available, it is often supplied to other crops also, including some such as grapes and olives, which will survive without it but are much improved in yield and quality if they receive supplementary irrigation. Other irrigated crops include vegetables, sugar beets, and alfalfa for hay and pasture. The irrigated land is used most intensively and is held in small farms that receive careful tillage and often represent a large investment of capital and labor per acre. Also it yields large returns. However, only a comparatively small part of the total area of the land classified as having Mediterranean agriculture is capable of irrigation, either because it is rough land not physically suited to that use or, more commonly, because there is not sufficient irrigation water available. The larger part must produce cereals under dry-land culture, or the more hardy of the unirrigated tree crops, or it is used as pasture land for more or less migratory flocks and herds. Since most of the Mediterranean climatic regions include areas of hills and mountains, these are used mainly as grazing lands, and they occupy much the greater part of the total area but support only a small part of the population. The dry summer pastures do not supply forage adequate for many cattle or horses but are much better adapted to the use of sheep and goats, which are the most numerous of the livestock kept there.

Adjacent to some of the Mediterranean agricultural districts of Europe and southwestern Asia are plateau uplands in which the winters are more severe so that the less hardy subtropical crops of the Mediterranean type are

mercial grain-farming regions part of the crop is raised by "dry-farming" methods. These are agricultural practices designed to conserve moisture by storing up in the soil part of the rainfall of more than one year, in order to produce a single crop. Thus the land is cultivated each year to make it permeable and retentive of moisture but is cropped only in alternate years. This type of farming is expensive in terms of labor, considering the possible returns, but it utilizes cheap land. It is particularly suited to grain farming because such crops as wheat and barley have relatively small water requirements.

The world regions of commercial grain farming, shown in Plate VIII, are, it will be seen, distinctive of regions of European rather than Asiatic type of civilization. They occupy the new and relatively cheap lands of the world, and most of them are bordered on their drier sides by regions of livestock ranching. In part they are regions of humid continental climate with warm summers, and these produce mainly fall-sown winter wheat, as in Kansas, Argentina, Australia, and the Ukraine. Some areas having the cool-summer type of continental climate raise mostly spring-sown wheat, as in southeastern Russia, western Siberia, the Prairie Provinces of Canada, and the Dakotas. Some specialize in grains other than wheat (Fig. 424). For example, corn is grown primarily for sale from the farm in a large district in eastern Illinois, also in the northern part of the Argentine grain region, and in the Transvaal and Orange Free State of South Africa. Rice, mainly a subsistence crop in the Old World, is grown entirely for sale under the American system of culture found in California and Louisiana, but these and some other cash grain districts are too small to be shown on the accompanying world map.

817. Associated Crop and Livestock Farming. This name may be applied to a mixed type of agriculture in which some crops are grown as feed for livestock, some for cash sale, and some as food for local human consumption. The relative importance of these three functional elements varies from one region to another. In

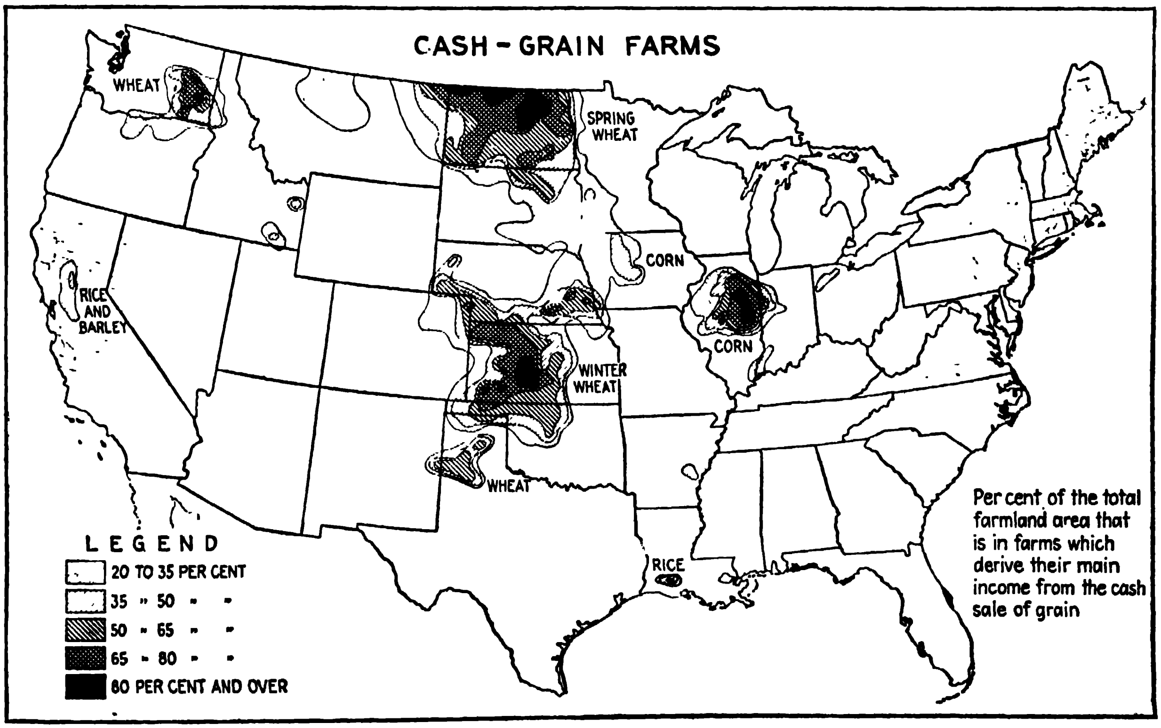

Fig. 424. Four principal areas in the United States, and several smaller ones, are characterized by farms whose main function is the production of grain for cash sale.

all the regions the production of livestock is highly important, but in some it is practically the only source of cash income. The mixed farming regions may in fact be divided into two types: (*a*) those in which crops and livestock are raised mainly for sale, and (*b*) those in which they are produced mainly for local use. These may be called the commercial and subsistence types, respectively (Plate VIII).

The commercial type of crop and livestock farming is best exemplified by the American Corn Belt, where crops are raised mainly to feed hogs, cattle, and sheep, which are sold from the farm and are themselves the principal source of cash. Relatively little grain or other crops are sold from the farm and even less is used for direct human consumption. In the western European region the emphasis is more evenly divided. The significant feature of this type of farming, however, is that it is organized upon a commercial basis and that it has usually more than one source of cash income but with one of them commonly predominant. In general this type of farm is more versatile than the cash grain type, and this in turn implies regions of better climatic endowment, particularly more abundant precipitation.

The farming system of the commercial crop and livestock type varies considerably among the regions. It has, however, certain distinguishable features. Outstanding is some sort of rotation of crops that employs a succession involving (*a*) a tilled crop, (*b*) a small grain, (*c*) a hay crop, and (*d*) rotation pasture. Thus, in the American Corn Belt the principal tilled crop is corn, the small grain is likely to be oats or wheat, and the hay crop alfalfa, clover, soybeans, or grasses. In a succeeding year the former hay field may be used as pasture before it is plowed up and the land used again for corn. Such a rotation may run 3 to 5 years and sometimes more. In south central Europe the sequence may involve corn, but in those sections where the summers are too cool for corn, it is replaced in the rotation by such tilled crops as stock beets, turnips, or potatoes, all of which are much used in feeding animals. In the districts of poor soil and colder winters also, wheat may be replaced by rye. In the level, dark-colored, prairie soils of the American Corn Belt the percentage of land under tillage is high, 75 per cent in parts of Illinois, Iowa, and Nebraska. In these areas a minimum of land is held in permanent pasture, but in regions of rougher surface and poorer soils, parts of eastern United States or Europe especially, the ratio of pasture land to crop land is much higher. However, the producing capacity of the land is high, and there normally is a surplus of feeds with which to fatten livestock in addition to those which are raised locally (Fig. 425). Additional animals usually are purchased from neighboring areas of lower rainfall or rougher surface. The American Corn Belt, the Argentine alfalfa belt, and various districts in France and Germany are noted as centers of livestock feeding.

The farms of these productive regions average smaller than those of the commercial grain-farming areas, 120 to 200 acres in the American Corn Belt, and much less in Europe, as compared with an average of 500 in the cash grain region in North Dakota. The manner of tillage is much more intensive, involving more investment, more labor, and a larger use of fertilizer. It is more expensive land, and the typical farm has larger and more expensive buildings to house animals and crops. According to the 1940 census, the average value of land and buildings per acre of land in farms was nearly $80 in Iowa but less than $13 in North Dakota. Also the average value of the farm buildings was nearly $4,000 per farm in Iowa but only a little more than $2,000 in North Dakota. The farm buildings in the central European mixed farming region also are large, substantial, and some of them very old as compared with the small and often barnless cabins or sod houses that characterize the farm settlements of the Russian wheat belt.

The subsistence type of crop and livestock farming are restricted largely to more primitive middle-latitude regions and especially to those which are remote from modern transportation routes. The largest region of this type is in central and eastern European Russia, where distances are great, railways and roads few, and the farming system derived from a very old form

of peasant agriculture. In that region rye and oats replace the wheat and barley that predominate in the commercial grain region of southern Russia. The rye and oats are mainly consumed locally rather than sold on the cash market. Other important subsistence crops include large quantities of potatoes and cabbage and some other vegetables. The livestock density is not high, but cattle, swine, and sheep exist in moderate numbers and contribute to the local food supply. Horses are used for farm labor. Most of the Russian peasant farms have been collectivized under the Soviet regime, and doubtless the subsistence type of agriculture is being broken down, especially near the growing manufacturing towns of the Moscow and Ural industrial regions, which furnish new markets for farm produce. The farmers of this region live mainly in villages, their principal construction material is logs, and their barns and other farm buildings are fewer and simpler than those of the commercial mixed farming districts of western Europe. Subsistence farming produces very little cash income with which to buy improved equipment.

Other regions of subsistence crop and livestock farming are smaller and less clearly defined. The isolated Russian settlements of central and far eastern Siberia have borrowed their characteristics in part from old Russia and may be considered similar in agricultural type. There are few such districts in Anglo-America, except possibly in parts of the southern Appalachian highland and Maritime Canada, and they are small. In the highlands of Mexico and in Central and South America subsistence agriculture of the ancient Indian type has been modified by the introduction of European animals. However, in most of these districts the animals do not belong to the people who till the soil but to the great ranch owners, although they may be tended by the humbler folk. In the Central Plateau of Mexico this is not true to the same degree. The cultivators of the productive basin lands also are the owners of donkeys, cattle, sheep, and goats which graze the dry hill slopes

Fig. 425. The buildings of a corn and livestock farm in Illinois. Storage for ear corn is in the low building (right) having doors in the roof for filling. The silo provides storage for part of the corn fodder. The feed yard contains about 50 head of fattening cattle and many hogs.

and furnish labor in the fields, a little meat, a little milk, and some wool to their owners. These farmers, like those of Russia, live mainly in village settlements, have simple houses and few barns or other structures and little in the way of mechanical equipment. They remain peasant farmers and practically self-sufficing. The Mexican plateau may therefore be classed as a region of subsistence crop and livestock farming. A similar condition prevails in the plateau region of southwestern Asia, especially in Turkey (Plate VIII).

818. Commercial Dairy Farming. Dairying is an intensive phase of commercial crop and livestock farming in which crops are raised to feed dairy cattle and other incidental livestock and in which milk and its products, rather than the animals themselves, furnish the principal source of cash income. Dairying is a more intensive use of land than beef production because a given quantity of feed will produce, through the medium of dairy cows, at least two or three times as much human food in the form of milk as it will in the form of beef. However, it requires more of the farmer's time and labor to produce it.

Commercial dairying prospers under varied climatic conditions, and it does not demand soils of the highest fertility. Pasture, hay, silage crops, and grain concentrates are required, but the industry is sufficiently remunerative that the concentrates may be imported if the coarser feeds are available. One condition commercial dairying must have, access to large urban markets. Milk and cream are so perishable that they must be marketed within a few hours of their production. Butter and cheese can be held longer, up to several months, provided there is means of refrigeration in storage and transit. The major dairy regions of the world are, as shown in Plate VIII, near the great industrial cities of northwestern Europe and northeastern United States and adjacent Canada. Dairying has not been traditional in the densely peopled subsistence farming regions of the Orient or in Mediterranean Europe with its poor summer pastures. Neither have the inhabitants of these regions the cash incomes that would enable them to support dairying on a large scale. Distant dairy regions such as those in Australia and New Zealand are of recent origin and have had the benefit of cheap land, efficient transportation, and protected access to the large British market.

The two major world regions of commercial dairy farming have advantages other than proximity to the great dairy markets. Relatively cool, moist summers are favorable to the production of pasture, hay, and other forage and fodder crops. They have also permitted the cultivation of oats and barley for grain and, in America, corn for silage. These are more suited to the feeding of dairy cows than to the fattening of beef and other meat animals. The average dairy farm in America is only slightly smaller (120 acres) than the crop and livestock farm, but its use is different. Less than half of it, on the average, is plow land, as against 50 to 75 per cent of the Corn Belt farm (Fig. 415). The average value of land and buildings per acre of farm land in the two regions is about the same, but in the dairy farm the large barns and other buildings are worth more than those of the Corn Belt farm and the land somewhat less. The difference in land values may be attributed to differences in soil, surface, and drainage, the dairy region being mainly one of gray-brown forest soils and recent glaciation, with areas of stony moraine and glacial marshes, which, however, are usable as pasture. The higher value of the dairy farm buildings is in consequence of the need for weatherproof structures for the protection of cows and forage crops and for the care of milk. Swine, poultry, and horses are necessary parts of the dairy farm livestock also and must be housed. Not all dairy regions require such elaborate structures. In New Zealand, especially, the winters are so mild that pasture is available all the year, no hay storage is necessary, and open milking sheds suffice for the protection of cows. There the benefits of cheaper land and lower housing costs are offset by high labor costs and especially by high freight charges to distant markets.

The form in which dairy produce is marketed varies within the parts of the great dairy regions also. Although there is no rigid separation, there is a tendency for those areas nearest the great cities to furnish the fluid milk while those farther removed furnish condensed milk and cheese, and the fringing areas supply butter. Thus, Great Britain, in normal times, is 100 per cent self-sufficient in fluid milk, about 30 per cent self-sufficient in cheese, but only 10 per cent self-sufficient in butter. The districts of New England, southern New York, and Pennsylvania supply the large eastern cities with milk, and southeastern Wisconsin and northern Illinois do the same for the Chicago metropolitan district. Northern New York State, the lower St. Lawrence Valley, and much of central and northern Wisconsin are noted for cheese manufacture, and Ontario, Minnesota, and other fringing districts are known for their butter output. In Europe, Denmark and the Baltic Sea margin are noted for butter production, but Netherlands and Switzerland, where dairy specialization is of long standing, have a large trade in cheese, for which they have become famous. Australia and New Zealand are noted for their production of butter, although the latter has a large cheese industry also.

819. Commercial Gardening and Fruit Culture. Another form of agriculture which depends upon the existence of the great urban markets is concerned with the supply of vegetables and fruits, both in and out of their usual season. These industries are a normal part of the Mediterranean agriculture, but they are found in other regions also (Plate VIII). The greatest markets are those of industrial Europe and North America. In those regions are millions of people who have not time or land for gardening, but they have cash incomes with which to buy horticultural products. The great population centers of the Orient, being more largely agricultural, supply themselves during the usual season and go without during the balance of the year, as did all the rest of the world only a few decades ago. The large cities of the Southern Hemisphere are not numerous and large enough to require either the great volume of produce that flows into the European and North American centers or so vast an industry to provide it.

The vegetable and fruit crops are the produce of highly intensive cultivation. The land area utilized is relatively small, but it is made to yield an astonishing quantity of food. It is heavily fertilized and tilled with a great expenditure of labor. The farms generally are small, and the nature of the farm operations does not require large or numerous buildings. In the typical horticultural district, therefore, neat houses with small barns and few outbuildings are spaced at short intervals in a landscape of intensive cultivation. The great markets are supplied by two somewhat different types of industry. One is local and the other distant. The first takes advantage of nearness to the market. Often these small farms are located on the outskirts of the market cities or within truck-hauling distance. They supply vegetables and fruits of great variety, each in its own season, but they operate under whatever disadvantages of climate and soil the region may have. The second type operates under the disadvantage of distance from market but reaches out for localities of special advantage in climate, soil, or other environmental conditions, each according to its own requirements. The first is likely to be a general horticultural industry, growing a series of fruits and vegetables simultaneously or in sequence as the climate permits or the market requires. This type of industry is sometimes called market gardening. The second type is usually more specialized, growing one fruit or one or two vegetable specialties upon which the whole year's operations are based. Such industries commonly are called fruit farming or truck farming (Fig. 426).

In both Europe and America the great cities have their distinctive market-gardening districts. Near New York City are the extensive gardens of Long Island and the Jersey shore, areas of light permeable soils that are easily tilled. Similar industries are found northwest of Boston, in suburban Chicago, and about most other cities,

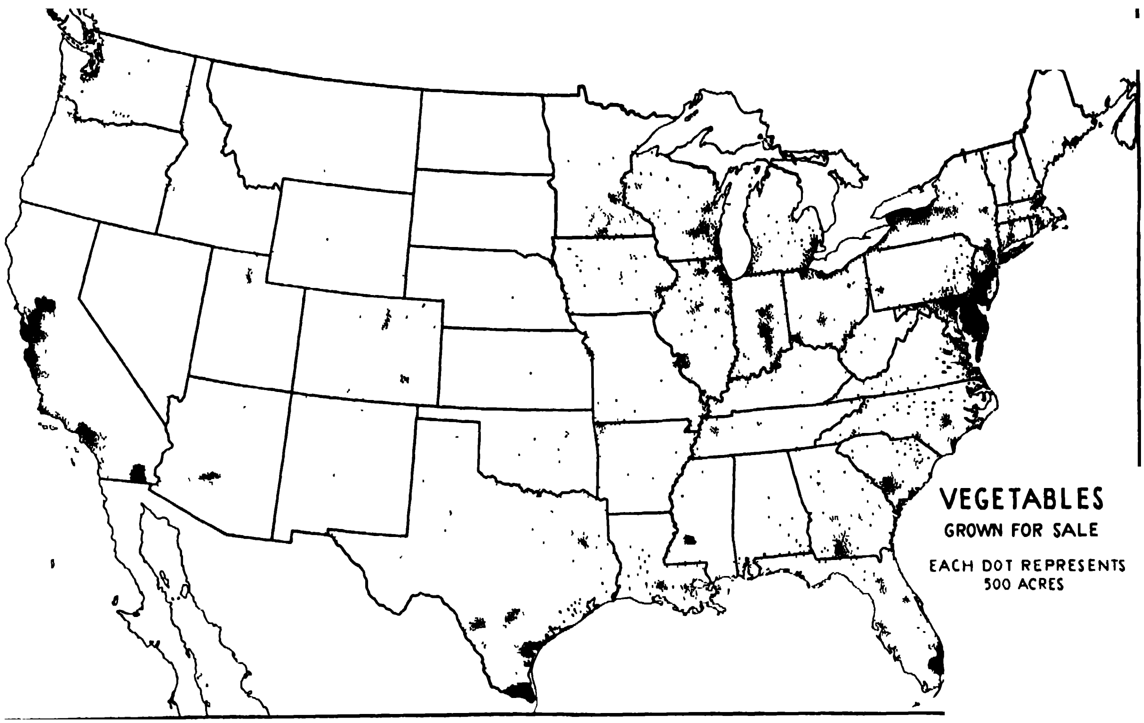

Fig. 426. The distribution of vegetables grown for sale reflects both the advantage of mild winters in the South and West and of special soils, or closeness of city markets in the Northeast.

roughly in proportion to their sizes. The truck-farming and fruit-growing areas, on the other hand, are farther away. Some take advantage of the temperature gradient from north to south to gain earliness of season. Beginning on the Gulf Coast or even in Cuba and Mexico, a wave of horticultural production sweeps northward through winter, spring, and summer, and finally merges with the garden products of the city environs. In Europe a similar zonal production begins in North Africa and creeps northward to areas on the channel coast of France, Belgium, Netherlands, and southern England. Many of the fruit-producing regions are highly specialized. Such are the irrigated apple districts of Washington, the peach region of Georgia, and the numerous wine districts of France. These in general are located with respect to some particular advantage of climatic condition which gives fruit of special and uniform quality year after year while that of less favored regions is variable in quality and quantity. Modern transportation has permitted even some Southern Hemisphere regions to compete in the northern markets. Apples, pears, and grapes from Argentina, South Africa, and Australia appear on United States and European markets in the season opposite to that of their normal production there, and thus they get prices that help to defray the high shipping costs. However, they are luxury items, and the trade is not large by comparison with that in wheat or some other agricultural staples.

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CHAPTER 31: *Manufacture and Its Associated Features*

820. The Function of Manufacture. The essential function of manufacturing processes is to change the *form* of materials for the purpose of making them more useful or more valuable. The change in form gives to the processed material what the economist calls *form utility*. Iron ore as it comes from the mine is practically useless, but after smelting, transformation into steel, and shaping into implements or machines, it is of strategic value. Cotton in the boll has little use, but after being ginned, spun into thread, woven into cloth, and the latter made into garments, it has acquired greatly increased usefulness and value through the application of energy and skill. It is so with a majority of the products of farm, forest, and mine. Only a few, such as certain vegetables, fruits, coal, etc., are ready for human use in their primary state.

821. The Use of Land for Manufacturing. One of the characteristic features of complex modern industrial regions, such as western Europe and northeastern United States, is the great importance of manufacturing which in those regions overshadows agriculture and the extractive industries, measured either in terms of the number of people employed or in the value of the output. In fact, in the whole United States, more persons are employed in manufacture than in agriculture and all the extractive industries, such as forestry, mining, and fishing, combined. In terms of total area covered, however, the manufactural features of large regions are much less conspicuous than are those associated with agriculture. This results from the greater intensiveness of the manufactural processes and, therefore, the possibility of concentrating them on much smaller areas. One square mile of the American Corn Belt usually includes about four farms. This means that 640 acres are operated by 6 to 8 workers and are supporting 15 to 20 persons. This same area, however, could contain several large factories, together with their fuel yards and storage facilities, employing thousands of workers. For this reason it is difficult to construct such a map as Fig. 427, showing the manufactural regions of the world. The centers of industry shown there include also much land used for agricultural, commercial, and residential purposes, and only a small part of the areas indicated is occupied by factories. It may well be true that the land actually occupied by all the manufactural establishments of the world could be included within one of the smaller American states, such as Connecticut, with plenty of room to spare. It is only locally, therefore, that the buildings and equipment of the manufactural industries are conspicuous elements of the landscape, but this fact need not mislead us with regard to their great importance.

822. Classes of Manufactural Industry. The United States Census of 1939 lists nearly 450 different kinds of manufactural industries, and doubtless the world list would include many more. Any attempt to compare the nature and significance of world regions of manufacture requires that industries be grouped according to some system of classification. Several such are in common use, each having its own point of view or purpose. One basic distinction commonly recognized is that which exists between the heavy and light manufactures, the former turning out such products as iron, steel, clay products, and heavy machinery, the latter such as small metal wares, textiles, or garments. Some industries also are classed as primary because they use only the crude products of the soil,

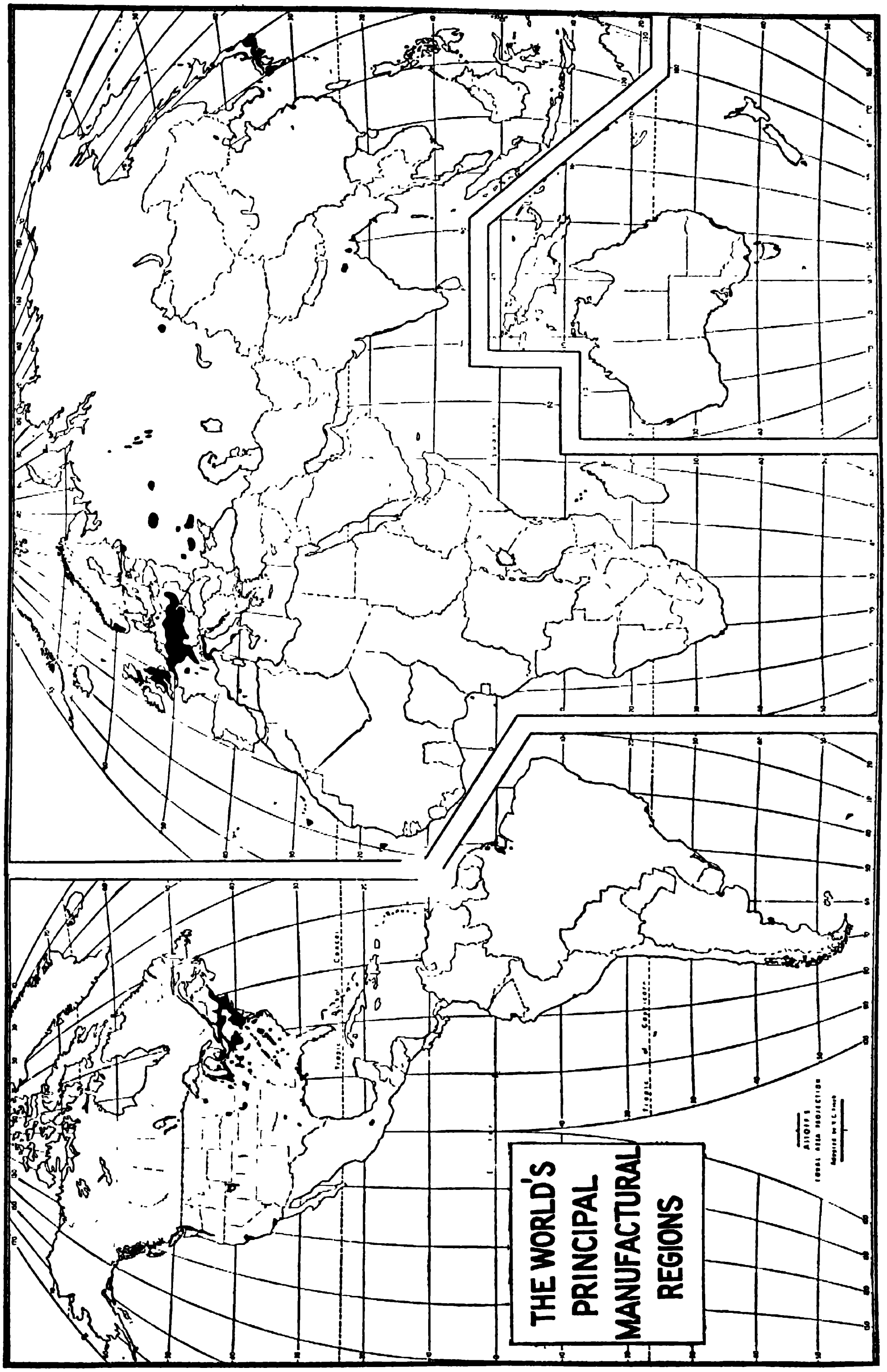


Fig. 427. The great manufactural regions of western Europe and eastern North America, by comparison, dwarf those of Asia and especially the small and scattered districts of the Southern Hemisphere.

forest, or mine as their raw materials. Many heavy industries are of the primary type. Other industries, especially the lighter ones, are called secondary because they employ the products of previous manufacture as their raw materials. The weaving of spun thread into cloth is a secondary industry, and so is the manufacture of a watch or an automobile from metals. These simple subdivisions fail at many points to give an adequate picture of the nature of regional industry. Other considerations are involved, and some of them are related to the nature of the industrial products. Such are the following: (*a*) The stage of completion to which the industrial products are carried; whether they are finished and ready for the ultimate consumer or are unfinished and require further manufacture. (*b*) The nature of the use for which the manufactured products are intended. There are several such distinctions to be made.[1] Some of the more important are (i) goods for immediate consumption, such as foods, newspapers, automobile tires, etc.; (ii) materials for construction, such as lumber, cement, and structural steel; and (iii) capital goods, which include such machines and permanent equipment as are used by manufacturers in the production of other commodities. (*c*) The durability of the products, whether intended for long-continued or for only temporary use. Still other considerations involve the nature of the raw materials from which the manufactured products are made and the sources from which they are drawn. Thus, some industries use mainly vegetable or animal products obtained from farms. Others use wood, metals, or chemicals drawn from forests or mines. A great many manufactured products include mixed materials drawn from various of these sources.

823. Measures of Relative Manufactural Importance. In judging the industrial character of a region for purposes of regional comparison it is necessary that types of manufacture be measured. The basis of such measurement can only be statistical, derived from published reports or from personal investigation. Fortunately the great industrial nations issue statistical reports in great detail. These make it possible to apply several methods of measurement, each designed to bring out its own type of comparison. Various classes of significant facts may be obtained from the statistics. Some of these are as follows: (*a*) Facts relating to the value of the things produced, such as (i) the value of the raw materials consumed, (ii) the value added by the process of manufacture, and (iii) the total quantity or value of the finished products. (*b*) Facts relating to the persons employed in the industry, such as (i) the number of wage earners and salaried employees, (ii) the total number of man-hours of labor in a month or year, and (iii) the total amount of wages and salaries paid per month or year. (*c*) Facts relating to the capital invested in plant, equipment, and other necessary aspects of manufacture. (*d*) Facts relating to the quantity and sources of the energy or power used. By using several of these measurements in combination, industries may be compared as to their relative importance in a region, or regions may be compared as to the relative importance of the several industries in them.

824. Classes of Manufactural Features. The factory or manufactural establishment is the point of convergence for the labor, capital goods, raw materials, and power and is the focus and heart of manufactural production, but it is by no means the whole of it. Surrounding the factory are the homes of the workers, and daily the employees move back and forth between homes and places of work. Workers in transit are a conspicuous part of the industrial scene at certain times of the day. Likewise converging upon the factory, carried by boats, railroad cars, or trucks, are large quantities of raw materials and fuel. These raw materials and fuels may not be very conspicuous at any one time, because they are a flowing rather than a stationary mass and do not remain in one place to be seen or measured like a building or a field of corn. The best that can be done is to express their bulk in terms of tons of coal, bales of cotton, or bushels of wheat, and these symbols are hard to visualize.

Just as raw materials and power resources are

[1] Charles A. Bliss. "The Structure of Manufacturing Production." Pp. 141–166. National Bureau of Economic Research, Inc., New York, 1939.

new factories employing many workers became much more numerous.

827. The Industrial Workers. In order to measure the relative importance of manufactural production as compared with other industries in a region, it is useful to have data showing what percentage of the employed population is engaged in manufacture. In the United States as a whole, for example, about 23 per cent are so employed, but in Massachusetts the comparable figure is about 36 per cent, and in Mississippi it is only 9 per cent. This is a clear indication of the much greater significance of manufacture in the regional complex of Massachusetts than in that of Mississippi. Before the Second World War, about 28 per cent of the working population of France was engaged in manufacture; about 40 per cent in England and Wales; but less than 20 per cent in Japan. In attempting to understand the industrial character of a region it is desirable to know also the proportion of its factory workers that are employed in each of its principal types of manufacture. For example, Fall River and Lynn both are cities in eastern Massachusetts and might, without study, be assumed to be industrially similar. However, the relative importance of their principal industries shows them to be essentially different. In Lynn, according to the 1939 census of manufactures, the three leading industries, measured by the number of persons they employ, were the manufacture of electrical machinery, of shoes, and of leather, and they employed, respectively, 46 per cent, 20 per cent, and 8 per cent of all the wage earners in that city. Fall River, on the other hand, had only two important types of industry. They are the manufacture of textiles, which occupied 63 per cent of the wage earners, and the making of wearing apparel from textile raw materials, which employed 29 per cent. That kind of comparison applied to other cities and industrial regions, at home or abroad, would prove highly instructive.

Conditions Affecting the Location of Manufacturing

828. Modern manufacture rests upon certain bases, some of which have already been noted or implied. Certain of these are inherent in the features of the earth, some others depend upon the economic structure of the existing social order, and still others are the result of vague historical beginnings or grow out of individual preferences, custom, or mere human perversity. It may be assumed, however, that enterprises resting upon the latter type of base are not so likely to persist as others that have natural and economic conditions in their favor.

829. Power and Fuel. Modern industry differs from that of earlier times mainly as a result of the use of mechanical power. The consumption of such power in the United States, especially, is enormous. It has been estimated that, per capita of the population, it is 50 per cent higher than that of Great Britain, twice that of Germany, 10 times that of Japan, and 150 times that of China.[1] The problem of producing and transporting so large a quantity of energy is tremendous, but obviously it cannot have the same industrial significance in all localities since not all have or use power of the same kinds or in the same quantities. The principal source of mechanical energy the world over is coal, and many factories are located so as to take advantage of local coal supplies. The other principal sources, petroleum and hydroelectric energy, are sometimes more available but not always so satisfactory because some industries, such as smelting, require a great deal of heat as well as mechanical power. How an industry may locate well with respect to sources of power and fuel depends upon the nature of the industry and its energy and heat requirements and upon the relative costs of these elements from different sources. One extreme is represented by industries, such as the ferroalloy minerals, which are large users of fuel and power but whose products are compact and comparatively valuable. They find it advantageous to locate near the source of energy. The other extreme may be seen in industries such as shoe manufacture, which uses comparatively little mechanical energy and whose products are bulky. They are mainly located with respect not to sources of power but to a combination of other factors.

[1] Energy Resources and National Policy. P. 8. National Resources Committee, Washington, 1939.

830. Raw Materials. The location of certain manufacturing establishments is best explained by their relation to the raw materials that they use. Some of these materials are bulky, and their volume is much reduced by the processes of manufacture. It is therefore more economical to process them near their place of origin and to ship them to market in more condensed form. Such an industry is meat packing. On the average, only about 60 per cent of the live weight of market cattle dresses out as edible beef. Therefore, to ship live cattle from the great feeding grounds to the centers of consumption would be wasteful, although it formerly was done, before methods of refrigeration in transit made it possible to ship dressed beef from packing plants in central United States, Argentina, and Australia. The same conditions apply in the lumber industry. Rough sawn lumber contains only about 40 per cent of the wood in a log, 60 per cent having gone as waste or by-products. Because of that, sawmills usually locate near the forests and ship their rough lumber, rather than establishing themselves near their markets and receiving shipments of logs from distant sources.

Other industries require only compact and easily shipped raw materials, but their products are bulky and expensive to ship. They tend to locate with little regard to sources of raw materials. The manufacture of glass bottles, fruit jars, and similar containers is an illustration of this type. Sand is the principal raw material, but the products are bulky and fragile. Silk manufacture is another industry that locates quite without regard to the source of its raw materials.

831. Labor. A supply of labor is a factor in the localization of industrial establishments, but not to the extent it formerly was. Some types of manufacture still require skilled labor, trained to special operations, but even these laborers can be moved in time, or new ones may be trained if other advantages offset the labor element. On the other hand, the increasing mechanization and simplification of industrial processes tend to reduce the dependence of industry upon an established group of workers to which the industry must move rather than moving the labor to the industry. In spite of this change, some types of manufacture still tend to cluster or group themselves in districts where a supply of trained or adaptable labor is known to be available. This is true of silk manufacture in the United States, for example.

832. Capital. Local interest on the part of men who had money to invest in manufacturing enterprises over which they could exercise personal supervision was formerly a potent influence in the localization of industry. To some extent it still is. The growth of corporate finance has, however, much reduced the importance of this factor. The great manufacturing establishments of modern times are located with little regard to the source of the money with which they are set up. That may, in fact, come from distant and diverse origins. In some countries the money and capital goods necessary for the development of industry are supplied by government and derive from taxation. Under such conditions the location of industry follows governmental desire and may be in response to political or military discretion rather than to the operation of economic advantage. However, some parts of the world have much greater surpluses of capital savings than others, and these are likely to have greater industrial development, other conditions being favorable.

833. Transportation. Modern industries require raw materials in great volume and from many sources, and they ship their products in large quantities to many destinations. For them good means of transportation are as essential as any other element in their environment. Formerly, the small home industries supplied the local needs, and little connection with distant places was necessary or possible. This gave rise to highly decentralized manufacturing industries, and even today a lack of transport facilities, as in China, tends to decentralize industry. Great establishments, on the other hand, seek localities that are well provided with railroads, highways, and, if possible, water routes. The more efficient, cheap, and dependable these means of transportation become, the greater is the tendency for manufacturing to concentrate in areas of peculiar advantage with respect to

other conditions. So potent is this factor that the great industrial centers are the great railroad centers also, and the growth of one promotes the development of the other. It is not accidental that the great manufacturing regions of America and Europe lie at the ends of the most used ocean route of the North Atlantic.

834. Nearness to Market. Although modern transportation permits the shipping of goods cheaply to distant places, there still remain real advantages in the location of a factory near to its greatest potential market, if other conditions permit. The first of these is cost of shipment. Although arbitrary rules relating to freight charges interfere to some extent, it generally is true that shorter distances mean lower transportation costs. The advantage to be gained from that is obvious. However, proximity of factory to market has other advantages also, particularly such as grow out of an intimate knowledge on the part of the manufacturer relative to the exact needs of his customers and of sudden changes therein. Thus, in the shoe industry, there are frequent changes in style necessitating corresponding changes in the machines used in shoe manufacture. As a consequence, most of the American shoe-machine industry is located in or near the regions of shoe production regardless of whether these are centers of general machine manufacture. Similar advantages have been influential in the location of textile-machine establishments in the spinning and weaving regions, and the manufacture of automobile parts and accessories in southern Michigan. There are many illustrations of this principle, in some of which the market to be served is the general public. This is particularly true in the case of such food products as are either perishable or bulky or both. Bakery products furnish an excellent illustration of that type of manufactured goods. It is true also of such products as have particular application to the interests of only one locality. Newspapers and job printing illustrate that type of product. Because of these conditions, bakeries and printing establishments are found in nearly all cities and towns, and they belong to that group of manufacturing industries which has been called "ubiquitous." Such industries typically are decentralized.

835. Other Factors. There are numerous factors, other than those named above, that play some part in the localization of manufacturing. Some of these are features of earth environment, such as a requirement for particular climatic conditions or for water supplies of great volume or special chemical quality. Others are of an economic or purely sentimental nature. Some industries locate adjacent to factories of an entirely different type because they use waste products from other mills as their raw materials. Some locate near others of their kind largely because the city or region bears a name famous the world over for their particular kind of product. The locations of still other industries can be attributed to nothing more substantial than the merest chance or accident. Actually, it is probable that in a large majority of cases two or more of the several classes of factors are concerned with industrial locations in a complex of relationships that cannot easily be understood.

The Great Manufactural Regions of the World

836. So many conditions are involved in the location of manufactural industries, and they are capable of combination in so many different ways, that it might appear that industrial distributions would almost be haphazard. To some extent they are so but by no means entirely. There is a recognizable grouping of the factory industries of the world into several major and some minor regional concentrations, and within these are districts of specialization that are of great importance. The oldest and most highly developed of these is in northwestern Europe. Next most important is that of eastern North America. Newer and much less complex are the centers of eastern Europe, the Orient, India, and the Southern Hemisphere (Fig. 427).

MANUFACTURAL REGIONS OF NORTH AMERICA

837. Although the American manufactural regions are exceeded in world importance by

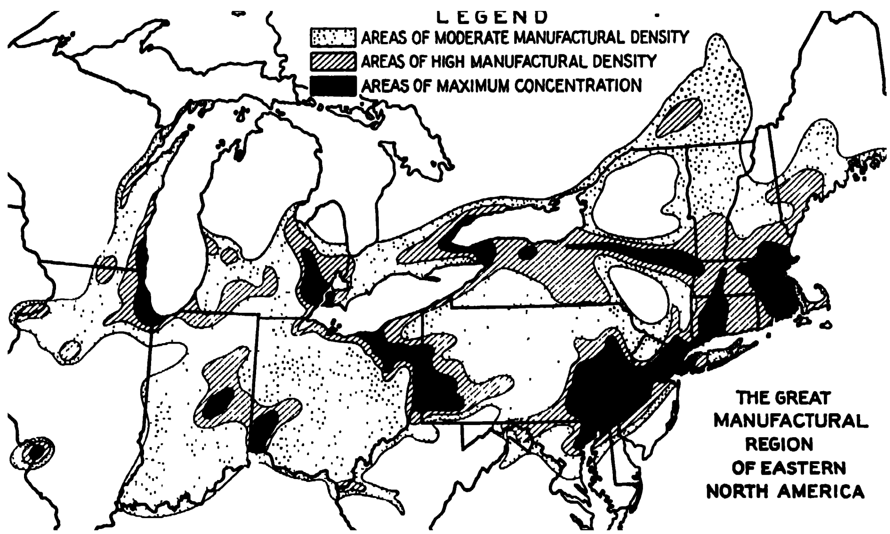


Fig. 430

those of Europe, they are remarkable for the diversity of their products, their rapid growth, and their areal concentration. Most of the cities and towns that are dominantly manufactural in type are located in a broad belt that lies in northeastern United States and southern Canada. Its boundaries reach from southern Maine down the Atlantic Coast to Baltimore; westward to Cincinnati, Ohio; northwestward to include Chicago and the industrial cities of southeastern Wisconsin; thence eastward across central southern Michigan, peninsular Ontario, and south of the Adirondack Mountains and the highlands of New England (Fig. 430). Within this area are concentrated more than two-thirds of the wage earners employed in manufacturing in the United States and Canada and like proportions of the industrial power used and of the value of manufactural output. Beyond the limits of this chief region are other centers of less significance in which the general-supply or "ubiquitous" industries hold a relatively more important place than in the major region. Of these, that of the southern Appalachian borderlands is most highly developed, whereas others in the central plains and on the Pacific Coast are newer and less devoted to the production of wares having general or world markets as opposed to local markets.

Many factors are concerned in the localization of these centers of manufacture, and their interaction has brought about regional specialization which, in many instances, is so striking as to give definite regional character. Even the major region is far from being a unit as to its type of development. It may in fact be subdivided into several areas of distinctive industrial character which differ in the nature of their principal industrial products and in the factors involved in their growth (Fig. 430).

838. The New England Districts. American factory industries were established in New England at an early date: textile mills in eastern Massachusetts and metalworking in the Connecticut Valley. Glaciation had produced numerous water-power sites suitable for the initial stages of industrial development; there was an abundant labor supply available on the overpopulated farms of hilly New England and French Canada, and capital had accumulated among the merchants of the New England coastal cities. The water powers of the Merrimac, Connecticut, and other streams still are used to capacity, but they have long since ceased to be adequate. Coal is brought in from Appalachian sources by coastwise shipping and by rail, but its cost and the lack of iron ores have worked against the establishment of the heavy industries in New England. Therefore the lighter forms of manufacture prevail. The early indus-

tries have been greatly elaborated and many new products introduced, but the original forms of manufacture still leave their impress in spite of growing competition from other parts of the country. Resulting from this heritage the eastern and southwestern sections of New England still show striking contrasts.

The eastern district, extending from Rhode Island to Maine, is dominantly one of textile, leather, and shoe manufacture, and the machine trades represented there are especially those required as necessary adjuncts of textile and shoe manufacture. Southwestern New England, in contrast, is a region of light metalware manufactures. Its outstanding products are hardware, tools, electrical equipment, firearms, aircraft, and machines, the outgrowth of metal trades established there more than a century ago. There are also paper, textile, and many other manufactures, but they are of less importance. Both these districts enjoy the advantage of proximity to the great eastern centers of population that are markets for part of their products, the southwestern district having particularly close relationship with the metropolitan and port area of New York City.

Because of the rapid wartime growth of manufacture in other parts of North America, the relative importance of the New England districts has decreased, even though the actual number of persons employed in all industries increased during the war period. The most significant decrease has occurred in New England's oldest factory industry, cotton-textile manufacture, which finds many advantages in the southern Atlantic states.

839. The Middle Atlantic Metropolitan Districts. The region that includes New York City, Philadelphia, Baltimore, and their immediate hinterlands has an unusual diversity of manufactures. These reflect the interaction of many forces, among which the outstanding are the commercial or port influence, the proximity of abundant coal in the northern Appalachian bituminous and anthracite fields, and the presence there of large centers of population, which furnish both local markets and abundant supplies of labor. New York City itself is a great manufacturing center, but it is first of all a port. Its outstanding products are of the secondary type, employing as raw materials the manufactured products of other regions, domestic and foreign. The best illustration of this class of manufacture is the clothing industry, which uses cotton, woolen, and other textiles purchased from New England and other weaving centers. Other examples are found in such industries as the refining of sugar, vegetable oils, petroleum, and copper. Some of these industries are of great size and have large plants which are concentrated in one or another of the smaller cities of the New York metropolitan area to which they give industrial character.

The secondary industries are important in Baltimore, Philadelphia, and other cities of southeastern Pennsylvania also, but relatively less important than in the New York area. This district has, on the other hand, a great industrial diversity since it includes many food-products industries, important textile, leather, and chemical manufactures and also some of the heavy industries, such as blast furnaces, steel mills, and the building of ships, locomotives, and machinery. Some of the raw materials for these diverse industries come from foreign sources through the ports of the region since they, and especially Philadelphia, are outstanding ports of import. This is true, for example, of hides, tanning materials, certain chemical raw materials, and even iron ore and other mineral ores.

840. The Central New York industrial belt, extending from Albany to Rochester, occupies the natural thoroughfare of the Mohawk Valley and the Ontario plain. Its cities have grown up along the Erie Canal and the New York Central Railroad, which link the eastern industrial districts with the Great Lakes and interior regions. The area has no local resource of coal, but the rich resources of the Pennsylvania anthracite and bituminous coal fields lie only a short distance southward, and the adjacent highlands furnish water powers that supply part of its energy requirements. It also is a region of great industrial diversity. The primary iron and steel industries are but little in evidence, and the same is true of the primary

textile trades. The secondary industries, however, are highly developed, and they include those which use many kinds of manufactures as their raw materials. Among the more important regional products are clothing, electrical and other machinery, optical instruments, chemical products, paper products, and printed matter. Some of these reflect a westward extension of the industries found in southwestern New England, but others are closely allied to those of the New York City area or of the Niagara region. This belt is clearly transitional in its position.

841. The Niagara-Ontario Region. Buffalo, Niagara Falls, and Toronto are the principal cities of an industrial region that reflects the advantage of location at the eastern end of the Great Lakes waterway. Cheap lake transportation permits the assembling there of grain and other agricultural produce from the interior, iron ore from the Upper Lakes region, and coal from the adjacent Appalachian fields. Industry in this region benefits also from the hydroelectric power of Niagara Falls and from its position on a main route between the interior and the eastern seaboard. The Canadian portion has also the advantage of a tariff barrier at the international boundary, which protects certain industries that might otherwise not exist. The leading industries of the region are of the heavy type and include blast furnaces, steel works, and rolling mills and the manufacture of machinery and vehicles. Of great importance also are the chemical industries, the milling of grain, and others that use agricultural products. From this it will be seen that the industrial character of the region is more nearly like those of the regions to the westward than it is comparable with the New England or seaboard districts.

842. The Pittsburgh-Lake Erie Region. In the Appalachian coal fields of western Pennsylvania and West Virginia the best and most abundant coking coals of America are found together with great quantities of fuel coals, some petroleum, and a large supply of natural gas. These resources gave a great advantage to the establishment there of the heavy industries, particularly the blast furnaces and steel mills of the early period of abundant steel production. The iron ore of the Lake Superior mines was unloaded at the Lake Erie ports and moved inland to the smelting centers, of which Pittsburgh was most important. Later improvements in the processes of ore reduction and a gradual decrease in the quality of the iron ores made it less necessary to move the ore to the coal region and more profitable to move coal and coke toward the sources of ore, especially to the ore-unloading points on Lake Erie. For these reasons Cleveland, Lorain, and places between them and Pittsburgh, especially Youngstown, Ohio, developed large iron- and steelmaking industries, and the area remains still the major center of such industries in America. In most of the cities of this region, one-eighth to one-half of all the wages paid to workers in all industries go to persons employed in these primary manufactures. Associated with them are other heavy industries also, such as the heavy machine trades and the manufacture of steel pipe, structural steel, clay products, pottery, and glass. This major interest does not exclude other kinds of manufacture, such as the important clothing manufactures of Cleveland, rubber manufacture in Akron, and others, but it does give an industrial character to the region which the changes of half a century have not been able to erase.

Although the basic resource of this region is fuel and power, its development has been promoted also by position with respect to Great Lakes transportation and the trans-Appalachian rail routes to the east.

843. The Detroit Region. Near the western end of Lake Erie is an industrial region whose center is Detroit, but it includes also a large section of southeastern Michigan, part of northwestern Ohio, and western Ontario. Like the south shore of Lake Erie, it enjoys the advantages of position between the Appalachian coal fields and the northern iron mines on Great Lakes transportation. It has also some of the basic industries of iron and steel production, but they are subordinated to those which use these metals and others as raw materials, especially in the manufacture of motor vehicles.

In Detroit and its industrial satellites the production of motor vehicles and their engines, bodies, and parts is the dominant industry. However, the region has many associated manufactures which include tools, heating and refrigerating equipment, electrical machinery, glass, chemicals, and many others. In addition to the advantages of Great Lakes transportation for the assembling of power and of mineral, forest, and agricultural raw materials, this area profits by immediate access to the great markets of the agricultural Middle West by rail and highway and also to the industrial East. The development of the Ontario section of the region has been further promoted by the tariff barrier at the international boundary.

844. The Cincinnati-Indianapolis Region. One of the important interior regions of manufacture includes the cities and towns of eastern Indiana and southwestern Ohio. It does not share the benefits of Great Lakes transportation or of direct access to the iron ores and forest resources of the Lake Superior region, but it has certain other advantages. It lies at the eastern end of the rich lands of the Corn Belt and between the Appalachian and eastern interior coal fields. To the Appalachian coal and industrial area it has access not only by rail but also through water transport on the Ohio River. Its diversified manufactures reflect an abundance of fuel and a variety of industrial raw materials, such as the products of the blast furnaces and steel mills of the Pittsburgh region and the grains and animals of midwestern and southern farms. They reflect also the large markets of the interior. In fact this region lies closest of any to the center of population of the whole United States. Highly important are its machine trades, including automotive and electrical equipment, precision tools, scales, cash registers, and many other types of mechanical products. Important also are the chemical and food-products industries, such as meat packing and the processing of grains, oil seeds, vegetables, and other agricultural raw materials.

845. The Lake Michigan Region. The western shore of southern Lake Michigan and its immediate hinterland comprise one of the major regions of manufacture in America. It is of great diversity, expresses the interaction of many factors, and is capable of division into several districts, which may not be considered here. Some of the principal factors include access to power resources by rail from the Illinois-Indiana coal fields and by lake transportation from those of the East. Other factors are access by lake to the northern iron-ore region, and the fact that it is the focus of rail transportation from and toward the agricultural lands of the interior plains, the Rocky Mountains, and even the Pacific Coast, which are its largest markets and its sources of raw materials. Chicago and Milwaukee are its principal centers. In them and in some of their associated towns are manufactures of nearly all classes, but a few groups of them reflect the principal industrial character of the region. These include blast furnaces and rolling mills (Fig. 428), which, like those of the Lake Erie shore, provide raw materials for many industries. Some of these latter supply the rural markets with automotive equipment, tractors, wire fencing, and a great variety of farm machines and implements. There too are the large meat-packing plants, grain-processing mills, leather tanneries, shoe factories, and other establishments that draw their principal raw materials from the western farms and ranches and find their markets both locally and to the eastward. Also in this region are manufactories of furniture, paper, and other products whose raw materials come, at least in part, from the forests of the North and the West. Being central in position and the focus of many railroads, this region produces also large quantities of cars and other railroad equipment.

846. Other Centers of American Manufacture. Although the great industrial region of the Northeast contains, as has previously been noted, more than two-thirds of the manufacturing strength of the continent, there are others of great importance. To some extent they are scattered throughout the South and West, but among them are districts of outstanding character, whose principal products reflect the resources and other advantages of the environs. Among them are the following:

847. *The Southern Highland Borders.* The southern Appalachian region furnishes both water power and abundant coal; it also has access to cheap labor, forest resources, iron ores, raw cotton, and other essential raw materials. It is not surprising that it has undergone industrial development. The principal expressions of this development are seen in the cotton-textile district of the Piedmont, the blast furnaces and steel mills of northern Alabama, and in wood-products and chemical industries. In general these localities are more specialized than those of the northern regions in the manufacture of primary products and have fewer of the secondary industries using these primary products as raw materials for further manufacture. This may be an expression of the lesser degree of industrial maturity of the southern region.

848. *Industrial Cities of the Central Plains.* East of the High Plains and extending from the Prairie Provinces of Canada southward to the Gulf of Mexico are widely spaced cities having considerable local importance in manufacture and not a small place in the whole industrial pattern of the continent. They include Winnipeg, Minneapolis–St. Paul, Omaha, Kansas City, St. Louis, Dallas–Fort Worth, and Houston. Most of them are first of all assembling points for regional produce, especially agricultural produce, and their leading manufactures are of the bulk-reducing type. Meat packing, grain milling, cotton compressing, oil refining, or similar industries take important places in them, and the more elaborate manufactures of secondary type are less developed. Of them all St. Louis is easternmost, largest, and most complex, since steel production, the machine trades, shoe manufacture, the chemical industries, and each of several others is important there, and some of them outrank meat packing which is usually a leading industry in cities of the Central Plains.

During the Second World War many of the interior cities west of the Mississippi River acquired new manufactural importance. War contracts brought them unaccustomed industries, including huge plants for airplane assembly. However, these did not serve greatly to increase the population of the region as a whole but mainly to attract workers from the farms to the cities. The number of persons employed as wage earners in manufacture in Kansas and Nebraska, for example, more than doubled between 1937 and 1944. The end of the war emergency greatly decreased such employment, and the generally subordinate position of the western central plains region in the over-all pattern of American manufacture remains little changed.

849. *The Pacific Coast and Western Interior.* Manufacturing industries in the far-western regions of Anglo-America reflect the interplay of many factors, physical and economic. Among these are (*a*) the nature of the local raw materials, (*b*) a scarcity of coal but an abundance of petroleum and of newly developed hydroelectric energy, (*c*) large nodal groups of population which constitute local markets and reservoirs of labor, (*d*) great distance from the eastern centers of manufacture, and (*e*) access to the trade areas and transportation routes of the Pacific Ocean.

There are three distinct manufacturing areas in the coastal region and two others of smaller size in the interior districts near Great Salt Lake and Spokane. Those near the coast include the Puget Sound-Willamette Valley group of cities, the San Francisco Bay groups, and the Los Angeles–San Diego group. In each of them are various industries which are concerned with the preserving, canning, and processing of perishable foodstuffs (fruits, vegetables, and fish) to prepare them for shipment to distant markets. Also there are many small industries designed to supply local demands, since the region is far removed from eastern factories which make similar products. In the northern group, from Vancouver to Portland, sawmills and wood-using industries normally take first rank. The mountain forests provide the raw materials for these important industries, and the streams provide electric power. Also, mountain and dry-land pastures support a sheep industry which provides raw material for a woolen textile industry in the Willamette Valley. The power

resource has been influential also in attracting other industries, such as the smelting and refining of aluminum and copper, the manufacture of aircraft, and the building of ships. All these are large consumers of electricity. In the San Francisco area, petroleum refining, steel products, and shipbuilding rank high. Other industries, such as sugar refining, reflect the great importance of the port, into which come raw sugar and other products from Hawaii and the Philippines. In the Los Angeles–San Diego region also diversity is characteristic. A large local market is served with much of its requirement in meat, clothing, furniture, machinery, and structural steel. Owing to advantages of climate, to its petroleum resource, and also to cultural and historical factors, three of the many industries take high rank. These are airplane and automotive assembly, the motion-picture industry, and petroleum refining.

Under wartime stimulation new industries were established in the Pacific Coast area, including blast furnaces, steel mills, and the manufacture of heavy machinery. Owing to these and to the enlargement of old industries, the local labor supply proved inadequate, and a large migration of population to the Pacific Coast took place. The number of persons employed in manufacturing industries in Washington and Oregon doubled, and that in California trebled, in the years 1937 to 1943. Many of these workers plan to remain, and doubtless some of the new industries may become permanent.

850. *The Pattern of Distribution.* Changes have taken place in the distribution of American manufacture, particularly as a result of a wartime economy. Yet, many of the changes are minor, others lack permanence or have already disappeared. It is true that certain industrial areas, such as New England, have experienced a relative decrease of position, while other areas, especially the Pacific Coast, have increased in importance. However, the number of persons employed in manufacturing in the Pacific Coast states was only 5.6 per cent of the United States total in 1937 and about 9 per cent in 1943. That does not indicate a revolutionary shift. Moreover, there has been no radical change in the location of those factors of basic raw materials, fuel, power, and population distribution, which are the factors in response to which manufacturing industries locate or relocate. Therefore, there has not been any sweeping change in the general pattern of manufactural distribution as shown in Fig. 430.

MANUFACTURAL REGIONS OF EUROPE AND ASIA

851. The continent of Europe is highly industrialized (Fig. 427). The Industrial Revolution of the eighteenth century found already there certain of the requisite cultural and physical conditions for a progressive and rapid development of factory manufacture. These included: (*a*) a large population having a fairly high standard of living, which provided a large potential market; (*b*) a high degree of technical skills, which had resulted from the perfection and specialization of household and small workshop manufacture; (*c*) inventive genius, which provided new machines and adapted them to the application of mechanical power; and (*d*) water power at first, and eventually steam engines driven by coal. There were also widely distributed sources of water power adequate for infant industries, and when these were outgrown, there were numerous coal deposits to replace them as primary sources of energy. Europe also had the advantage of more highly developed routes of transportation than any other part of the world; good highways, canals, and canalized rivers, and a deeply indented and estuarine coastline that made large parts of Europe accessible from the sea Under modern conditions coal is the primary source of mechanical energy, and water power takes second place. The near absence of petroleum in western Europe, significant as it may be from the standpoint of transportation and war needs, has little relation to the growth of industry since it is not, even in the United States where it is abundant, a major source of energy for manufacturing industries. It is not surprising, therefore, that the heavy and basic industries of Europe, which require great quantities of energy and fuel,

are clustered about the richest coal fields (Figs. 358 and 359). There are commonly associated with them many other kinds of manufacture which find various advantages in being in the great centers of industry. However, there are also several lesser manufactural districts in which the lighter forms of industry predominate, especially such as do not require great quantities of fuel and power in proportion to their demands for labor and capital or to the value of their products. Some of these are associated with the smaller and poorer coal fields or are dependent upon modern hydroelectric or steam-electric power installations. They include especially the textile manufactures, chemical industries, and many others of the lighter type.

Because of the conditions that have affected industrial development, the manufacturing centers of Europe are by no means uniformly distributed. The major districts are, in fact, arranged in a more or less continuous belt that extends east and west through the middle portion of the continent. Northern Europe, on the one hand, and the Mediterranean borderlands, on the other, are much less well endowed and less industrialized. The principal belt includes Great Britain, on the west, and extends through northern France, Belgium, western and central Germany, Czechoslovakia, and southern Poland into central and southern Russia. Various portions of industrial Europe will be given further consideration.

852. British Centers of Manufacture. In Great Britain coal is abundant and other sources of power scarce. It is natural therefore that the great industrial centers of the nineteenth century grew up about the coal fields (Fig. 358). To a large degree this association still exists, although new factors have come into effect and shifts are taking place.

The early iron industries of England were located especially in the Midlands region near Birmingham, and this region remains highly important in the manufacture of machinery, vehicles, arms, hardware, glass, chemical products, and many other things. Although the region has less local coal than some of the others, it has the great advantage of central location and excellent railroad connections. Power brought by transmission lines from steam-electric plants in adjacent coal-producing districts is supplemented by hydroelectric power and helps to overcome the disadvantage of a declining local coal resource.

The same flexibility with respect to power supply that has been made possible by electric transmission has aided also in making London a great and diversified manufacturing center in recent decades, although it has no local coal whatever. Its coal supply must come from the northern fields by boat and train. Formerly it was the great commercial center and port of Britain, but its manufactures were restricted and concerned mainly the processing and repackaging of a variety of products imported from abroad and designed for reexport to foreign markets. The vast labor supply of London, its connection by rail and water with the other British ports and centers of raw materials, and its ability to secure power have attracted to the city and its suburbs, in recent decades, many of the newer types of chemical and metal manufactures as well as shipbuilding and some other of the heavy mechanical trades. Efforts have been made, however, to scatter and decentralize the industries of London in order to reduce the losses caused by aerial bombardment in the war. To some extent the scattering may be permanent, and London may not again be the great center of British manufacture that it has recently been.

In northeastern England is the principal region of heavy industry. It is located in association with the coal fields of Northumberland and Durham and one of the several principal domestic sources of iron ore in the Cleveland district of northern Yorkshire. Coastal location also favored manufactural development in this region since Swedish and Spanish iron ores came in through convenient ports, and many of the regional products were exported. However, exports have declined and so have the imports of ore and other raw materials, especially under war economy. As a consequence the coastal towns have suffered some industrial depression while the inland transportation

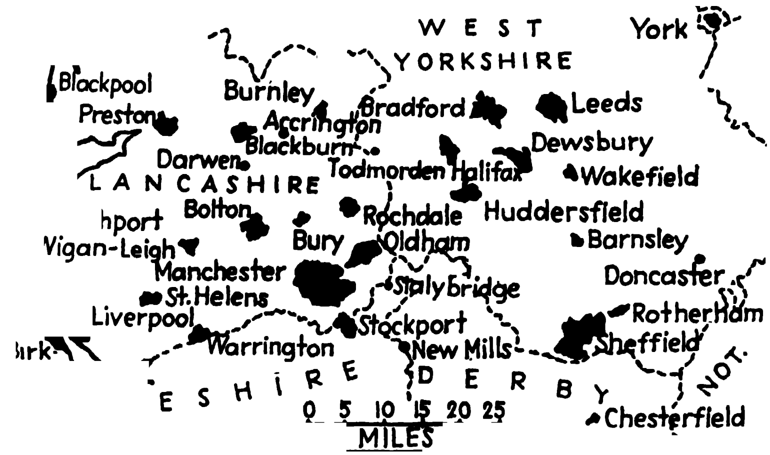


Fig. 431. Important towns in the Lancashire-Yorkshire industrial region of England.

centers have experienced comparative advantage. Important centers of manufacture in this district are the great steelmaking towns such as Middlesbrough and Hartlepool. Newcastle-on-Tyne has long been a major shipbuilding port, but the region is also a producer of railroad and structural steel, locomotives, cars, and other heavy goods. It has also a variety of lighter manufactures, including chemical industries, which are based in part upon local salt deposits.

Associated with the productive coal fields of Lancashire and Yorkshire, which lie, respectively, to the west and east of the Pennine Hills, are industries of quite different type. These are the great centers of textile specialization. Sheep were numerous in the hilly uplands, and the manufacture of woolens was established there at an early date. When cotton spinning became important, and especially after the growth of large factories, American cotton was conveniently brought in through the west-facing port of Liverpool, and cotton textiles came to dominate the manufactures of Lancashire. For various reasons wool manufacture shifted to the eastern side of the Pennines and concentrated in western Yorkshire. A high degree of specialization grew up in both these textile regions, some towns spinning yarns of special kinds and others making only a limited class of fabrics (Fig. 431). However, such extreme specialization was a disadvantage during depression years, and the larger and more centrally located places had an advantage, while some of the smaller and more specialized experienced extreme distress for which the British Government is trying to find a remedy in regional diversification and development. The textile industries, especially cotton, have been slow in recovering from prewar depression and wartime restrictions, and the textile centers are most subject to change. An industrial relocation is now in progress. The metal trades have long been represented in this region also, especially in Sheffield, where charcoal steel and an excellent variety of grinding stone gave rise to the cutlery industry for which that city has long been famous. In more recent years, abundant coal and the iron ores of western Yorkshire and other deposits of eastern England have encouraged its expansion into one of the important steel-producing districts of the country.

Britain's most northern manufactural region lies in the Scottish Lowlands, between the River Clyde and the Firth of Forth. It is based upon the coal deposits of that area. It is a region of great industrial diversity but is noted particularly for its iron and steel products and its textiles. The former find particular expression in the shipbuilding of the River Clyde, near Glasgow, where the largest ocean liners are built and equipped. The region also includes famous centers of manufacture in cotton, wool, flax, and jute.

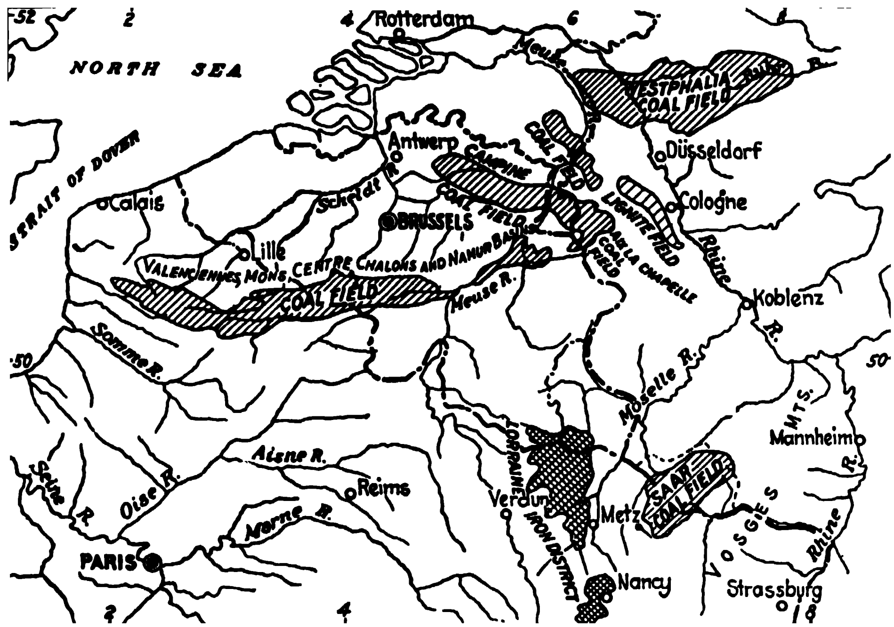


Fig. 432. The principal coal fields of France, Belgium, and western Germany in their geographical relations to the great iron-ore deposits of Lorraine (see also Fig. 372.)

The industries of the South Wales coal field are more recent and specialized than those of the other coal regions. Blast furnaces and rolling mills furnish raw materials for the manufacture of steel plates and tin plate, which are the most distinctive products of the area.

Prewar depression, wartime destruction of plants and facilities, and the ensuing reconstruction have combined to bring about numerous changes in British industrial locations. New industries and shifting old ones seek space in the vacant plants of the depressed areas, in wartime munitions plants, and in new building. However, these are mainly changes of detail, involving a large number of small manufactures. Social planning and relocation in their broader aspects cannot overlook the areal distribution of those basic resources and conditions upon which British industry rests.

853. French and Belgian Centers of Manufacture. On the continent of Europe, the industrial districts of France and Belgium comprise the westernmost units in the great manufactural belt that extends eastward through central Germany and into Russia (Fig. 427). All the districts are related to the sources of power and minerals found in that part of the continent (Fig. 432).

The focus of French industrial development is in the northern and northeastern parts of the country. It comprises a broad belt that extends along the Belgian, German, and Swiss borders. The reason for this is found in the distribution of the critical mineral and power resources. France is not supplied with large reserves of good coal, but there are large and well-integrated water powers. These are obtained from the bordering highlands of the Ardennes, Vosges, Jura, and Alps, and also from the Central Highland and the Pyrenees. Water powers are therefore available in many parts of France but especially in the northeast and east, where they are well used in the development of textile and other light manufactures. Water power is, however, inadequate for the support of heavy industry. The principal coal deposits of France are in the north, where they are continuous with those of Belgium. They supply fuel for the heavy industries in and near the coal fields, but in recent times the fuel requirements of French industry have been fully met only by importing coal from

England through the northern French ports. In the north of France also are the great iron-ore deposits of Lorraine (Fig. 432). These, in combination with the coal, are the basis of the heavy industries. In part the ore moves to the coal, and steel mills are located in the north of France and in the heavy industrial belt of Belgium, which extends along the coal fields from Mons to Liége. This belt includes not only iron furnaces but also zinc smelters and other metallurgical industries together with machine manufactures, glass, clay-working, and chemical industries. In addition to its coal this region has a dense population from which to recruit an abundant labor supply. Not all the iron is smelted in this district, however, because much of the high-grade coal moves eastward to meet the ores of Lorraine, which are rather low grade and therefore bulky. This trade is the basis for the growth of heavy industry in the ore-producing region. Since 1945 the coal basin of the Saar has been under French influence also, and it is located closer to the iron ores of Lorraine than are the coal fields of northern France and Belgium.

Many lighter industries also have located in and adjacent to the coal fields. Such are the textile mills of the lowlands of northern Belgium and of northern France. These industries are, however, not so closely dependent on coal as are those of the heavier types, and they are found also in eastern France and in many other sections where water power is available.

Paris, like London, is a great center of manufacture even though it has no local source of power. The fact that it is a transportation center and is able to furnish a large labor supply is sufficient to attract many industries to it, but mainly those of lighter type.

854. Western Germany has several highly important industrial districts, including those of the Saar coal basin and the upper Rhine Valley and Bavaria, but the most important are those of the lower Rhine region, which are associated with the productive coal fields of the Ruhr Valley in Westphalia. This is the oldest and probably still the largest center of German heavy industry. In the Westphalian district are more than a dozen industrial cities exceeding 100,000 population each and numerous towns of smaller size (Fig. 433). Among them, as in parts of Great Britain, is much industrial specialization. The heavy industries are grouped on the coal fields (Fig. 432) and to the east and southeast of them, the hardware and lighter metal trades lie southward, and the textile districts have developed to the westward and northward. For example, heavy iron and steel wares are the typical products of Essen, Dortmund, and Bochum in the coal area. Hardware, arms, and cutlery are the distinctive manufactures of Remscheid and Solingen, a variety of textile products is more characteristic of Duisburg-Hamborn, Krefeld, München-Gladbach, Köln (Cologne), and several others. In some part of this great Rhenish-Westphalian region are factories producing nearly every class of goods from silks to ships.

The manufactural centers of western Europe have been for decades peculiarly subject to the fortunes of war. For example, during many years prior to 1918 Germany controlled and its industry drew heavily upon the iron ores of Lorraine. That control was lost in 1918, regained in 1940, and lost again in 1945. Moreover, the coal mines and industrial centers of northern France and Belgium have been repeatedly damaged by invading armies. During the Second World War the cities of the Ruhr-Westphalian region were frequent targets for Allied bombing raids, and the resulting devastation is widespread. However, the coal deposits still are there, some factories were little damaged, and others have been repaired. Judging from the measure of recovery now completed, it is likely to be found that the same physical and economic forces which asserted themselves in the first place will have done so again. So great an industrial region cannot be completely and finally erased by the action of war alone however much it may be changed in detail.

855. Central European districts of manufacture include those of south-central Germany and Bohemia. They are associated with large deposits of lignite, scattered small deposits of coal, sources of water power and various min-

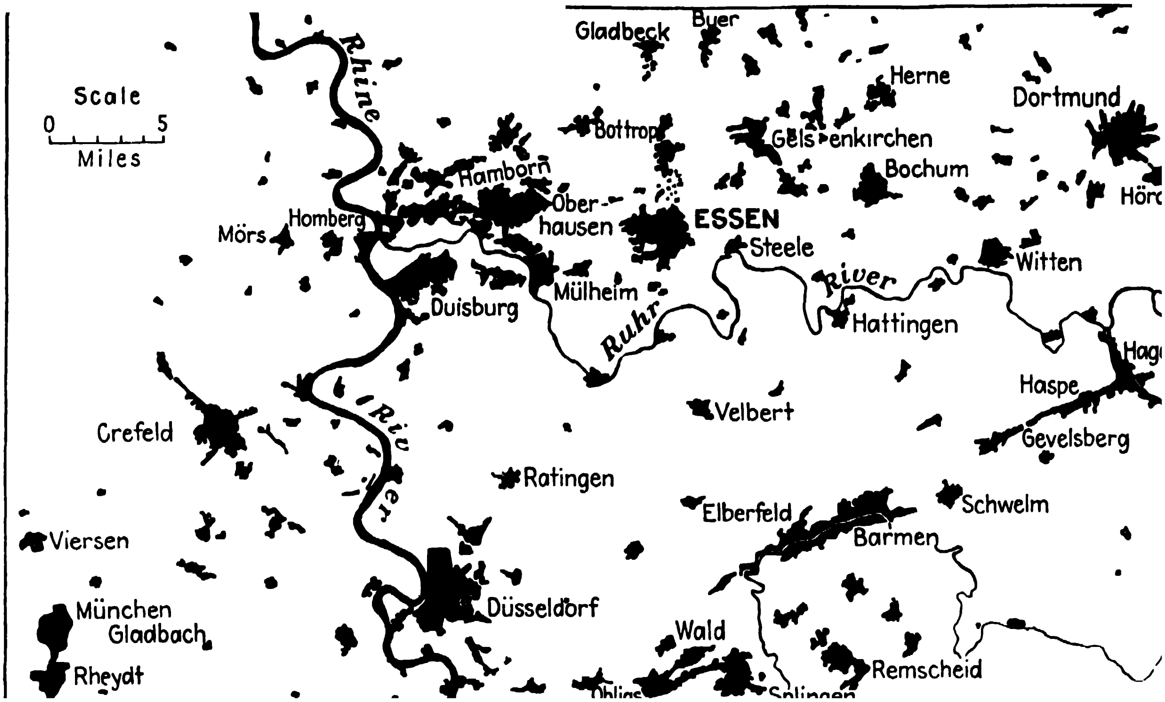


Fig. 433. The principal towns of the Rhine-Westphalian industrial region.

erals, especially low-grade iron ores and the great German potash beds. Lignite is employed in the production of synthetic gasoline, and energy derived by various means from lignite, coal, and water power is integrated into a highly efficient power network. This central power resource and the exposed military position of the Westphalian region has caused a shift of industry to this more distant interior. The iron ores serve as a foundation for heavy industries, including some of the newest steel works. However, the low quality of the ores generally makes it necessary to improve them by the use of high-grade ores, especially those imported from northern Sweden. Potash and the products of coal and lignite distillation form the basis of highly developed chemical industries. The older products of the region are mainly of the lighter types, such as textiles, pottery, light machinery, optical goods, precision instruments, and the products of engraving and printing. These are the wares upon which the high industrial reputation of the region was made, and they remain important. A new political dispensation brought others which included armament, automotive, and airplane manufactures. All were knit together into a new kind of interdependent manufactural region. Much of the shift from the west appears to have been designed as a military precaution and seems uneconomic in view of the meager supply of coal and the low-grade iron ores. Now this industrial area is mainly within the zone of Russian control. How much of its former structure and importance may remain only the future can tell.

In Silesia there are coal, zinc ore, and some resources in iron and other minerals. These have permitted the growth of metallurgical industries around which other manufactures, including textiles and clothing, have gathered. This area, which between 1918 and 1939 was shared by Germany, Poland, and Czechoslovakia, was developed by all three countries. Now it is largely within the boundaries of Poland. It has also a most advantageous position on natural north-south corridors of central Europe, such as the Moravian Gate, at the western end of the Carpathian Mountains, and the Elbe Valley.

All these and other smaller centers of manufacture merge with those of western Germany, Belgium, and France in a nearly continuous belt of high manufactural development which occupies a strategic place in the industrial pattern of the world. In fact, it is a belt of such high population density (Figs. 382 and 389) and manufactural concentration that, prior to the Second World War, it had no equal in industrial importance in any other continent.

856. South European Centers of Manufacture. Lack of coal in southern Europe has not prevented manufactural development there but has notably affected its character. Spain has abundant iron ore but little coal, and Switzerland, Italy, and the Balkan countries have no important reserves of either. However, the Alps and the Pyrenees furnish water powers that are used intensively. For that reason the heavy industries are not highly developed, and those which exist depend largely upon imported coal and raw materials. They operate in large part under government promotion and for political or military reasons. These include shipbuilding and airplane manufacture, especially in Italy. Deprived by wartime blockade of their supplies of fuel and scrap iron, they were quickly reduced to relative unimportance. The more typical industries are of the lighter kinds. These include food preparation, textile manufactures, and fine metalwares, such as watches and instruments. These industries and many others can utilize the hydroelectric power and the abundant skilled labor of the Swiss valleys, the Po Basin of Italy, and Catalonia in northeastern Spain. The Balkan Peninsula is poorly developed in manufacturing. It has little coal, its water powers are much less than those of the more rainy and glaciated Pyrenees and Alps, and its people have long been troubled by political unrest that has not given manufacture the necessary condition of security.

857. Regions of Manufacture in the Soviet Union. The vast expanses of Soviet Russia contain many of the requisites of a large-scale manufactural development. Prior to the Soviet regime, however, they were but meagerly employed. Large reserves of coal exist and also petroleum, iron ores, manganese, and other raw materials such as metals, timber, and agricultural products. The intense effort to achieve industrial independence initiated by the Soviet government brought about the use of these on a much larger scale than formerly, and several industrial districts have developed (Fig. 427). In part these were associated with the coal deposits of the Donets Basin and the Moscow region, supplemented by water powers obtained from the mountain streams of the Caucasus and from large streams of low gradient such as the Dnepr (Dnieper) (Figs. 359 and 360). In the Donets Basin particularly, the proximity of the great coal fields to the iron ores of Krivoi Rog led to the development of the heavy industries, and such cities as Kharkov, Lugansk, Rostov, and others in the south made great industrial advancement. They specialize in machinery, tractors, farm equipment, and similar products. Much of the industrial potential of southern Russia was ruined during the German invasion of the area, even including the great Dnepr dam, but is being restored because of the industrial resources there. Moscow, on the other hand, is the center of an old region of manufacture, but it suffered from a lack of coking coal and iron ores close at hand. It was formerly noted for textiles and other light manufactures, but because it is the chief city of the country, has a large labor supply, and is the principal rail center it has attracted a great variety of manufactures, some of them of the heavier type. Its great size and diversity make the Moscow region the greatest industrial center in Russia. Leningrad ranks second, but not because of its abundance of coal. It has, in fact, no coal and must bring its supply at great cost from the south or from foreign sources. It has more water power than Moscow but few raw materials save timber and some agricultural products. Its great development as a manufacturing center has depended largely upon its strategic position as the gateway to the Baltic Sea, the only convenient seaport of all northern Russia opening toward the industrial countries of western Europe. Fortunately for Russia, military precaution and the desire to bring to distant regions the benefits of

manufactural industry had established other industrial centers far to the east. There are two of these, and each shows clear relations to the resources of its district. The first lies in the southern Ural region, which has a variety of resources but none in great abundance. Some small deposits of coal are found there and high-grade iron ores, copper, lead, potash, salt, and other industrial minerals. Ore reduction, machinery and arms manufacture, chemical industries, and many others supplement those of the Moscow and other western districts. They also have the merit of being 800 or more miles east of Moscow and thus less exposed to military invasion. The most critical shortage of materials in this region is of good coal, although some of the small deposits are of high quality. Its greatest surplus is of iron ore, mined near Magnitogorsk, and this is to some extent exchanged for coal with the central Siberian industrial district of the Kuznetsk and Karaganda basins (Fig. 360), which have coal in abundance but little iron ore. The Kuznetsk industrial region lies 2,000 miles east of Moscow, and although its development is recent, it may prove of critical importance. Not only does it manufacture metal products, but it has also at least the beginning of chemical, wood products, paper, and general-supply industries. It has as its markets the growing population centers of central Siberia and the eastern Pacific maritime region.

858. Regions of Manufacture in Eastern and Southern Asia. The relation between coal deposits and the location of manufactural districts so commonly observed in Europe and America appears to be less conspicuous in the Orient. The great coal fields of northern China have no associated manufactures, whereas the high industrial development of Japan has comparatively little coal to support it. For an explanation of these facts one must turn to the industrial history of the two countries and to their comparative accessibilities from the standpoint of transportation.

859. *China*, at the beginning of war with Japan in 1937, had barely passed the threshold of modern industrial development. Such modern factory industries as it possessed, largely textile mills, were concentrated in the densely peopled lower Yangtze Valley. They drew their coal from several small fields difficult of access. The great coal fields of Shensi-Shansi (Fig. 361) have inadequate railroad facilities and have as yet contributed very little to the supply of industrial power. War devastated the factories that did exist and set Chinese manufacture back almost to the handicraft stage. Developments that may bring about regional concentrations of industry remain for the future to unfold. Only a beginning is now being made, and civil war has served only to postpone recovery.

860. *Japan* has only small coal fields, but they are readily accessible, and both rail and water transport permit of the movement of fuel to the centers of population. There are also widely distributed and highly developed water powers, and a great Japanese merchant marine formerly existed to assemble raw materials and distribute manufactured exports. Moreover, a large and rapidly increasing population provided cheap and abundant labor and almost enforced modern industrialization in spite of meager resources in coal and iron. As in nearly all countries, the earlier and larger part of the manufactural development took place in the field of the lighter industries, especially silk and cotton manufactures, food preparation, and small wares of wood, paper, and metal. However, there was a great change in the character of Japanese industry in the last quarter of a century and particularly within the decade prior to the Second World War. It expanded into many new fields. Faced with the competition of rayon against the silk industry, Japanese manufacturers themselves set up rayon industries exceeding those of any other country. The textile trades were extended also to include wool and other fibers. It was not, however, in the lighter industries alone that expansion took place. Abundant water powers, cheap labor, a depreciated currency which made it difficult to buy foreign manufactures, and the desire to become independent of foreign sources of critical military needs combined to promote the heavy industries in spite of deficiencies in the natural equipment of the islands. In order to support growing steel

industries and engineering trades it has been necessary greatly to increase the coal output of Japan's limited deposits and to import coal from foreign sources. Because the home supply of iron ore is even more limited than that of coal, it became necessary also to import pig iron from Manchuria, ores from China, Malaya, and Australia, and even larger quantities of scrap iron and steel in order to avoid the use of so much coal in the smelting process. These conditions, together with the lack of domestic petroleum, made the new Japanese economy particularly vulnerable.

Among the heavy industries were several of large capital and great scope. They included shipbuilding, hydroelectric and other machine equipment, and a variety of chemical industries, which are quite different from the small plants and light manufactures of the earlier period. The districts of manufacture are largely concentrated in the "industrial belt" of southern Japan. It extends westward from Tokyo to the coal fields of northern Kyushu and includes the large cities, Yokohama, Nagoya, Kyoto, Osaka, and Kobe.

861. *India*, like other lands of ancient civilization, has a long tradition in the handicrafts. For many years also factory industries have been established, especially in the textile trades, and to some extent also in metalworking. The first to develop on a large scale were the cotton mills of the Bombay district of western India. Subsequently jute mills were set up in the Calcutta region, near the source of the raw fiber. The rise of heavy industry in India is, however, of recent origin. The vast deposits of high-grade iron ore in the district northwest of Calcutta and the nearby coal fields invited the establishment of blast furnaces and steel mills of modern type, although the coal reserves are not great. The large supply of cheap labor makes it possible to produce iron there at very low cost. Until recently, however, it supplied mainly the domestic market for machines and implements. The emergency of war found in the Indian factories a nucleus capable of rapid expansion, and they quickly became an important source of supply in a variety of goods. Not only textile and leather products were provided for the armed forces, but guns of various types, explosives, vehicles, and small marine craft, and a surplus of crude iron and steel was exported for manufacture elsewhere. India may, therefore, be counted as one of the important and growing manufactural regions of the world.

MANUFACTURAL REGIONS OF THE SOUTHERN HEMISPHERE

862. The more settled portions of the Southern Hemisphere are mainly producers and exporters of agricultural and mineral raw materials but have not engaged in their manufacture on a large scale. Hence, there are no great industrial centers there. It does not follow, however, that factory industries are entirely undeveloped or incapable of expansion. The South American countries, which have the largest domestic markets, are handicapped by lack of coal, while Australia, New Zealand, and South Africa, which have some coal (Fig. 362), have only limited markets because of small populations. In all these areas, however, manufacture has made beginnings, and in some it has advanced considerably (Fig. 427).

863. In Argentina and Brazil the principal factories are those concerned with the preparation of foodstuffs and with textile manufacture. It would be expected that the forms of manufacture that could succeed there would be (*a*) those using raw materials produced in the region, (*b*) those using a comparatively small amount of coal-driven machinery, (*c*) those demanding a relatively small force of technically skilled employees, or (*d*) those producing articles that require local manufacture in order to fill immediate needs or to fit the exact nature of the local markets. In Argentina, where there is little water power and all the coal must be imported, the principal industries are meat packing, flour milling, textile mills, and manufactories of vehicles and farm implements to fit local needs. They are located mainly in the great city and port of Buenos Aires. Brazil has the advantage of large water-power resources and of a larger domestic market, and it has somewhat more diversified manufactures which include cotton

and jute textiles, clothing, chemicals, and some metalwares. Through lack of coal, however, there has been only a little progress in the utilization of the large domestic resource of iron ore. One modern blast furnace and steel rolling mill has been built at Volta Redonda in the eastern highland not far from Rio de Janeiro, but its operation must depend in part on imported coal.

864. In Australia and New Zealand, as in South America, the settlement and development of a large area of land by a small population has only recently permitted much attention to be given to manufacture. However, conditions there have favored manufacture somewhat more than in South America. In addition to supplies of coal there is the factor of greater distance and higher freight rates from the European and American manufacturing regions. Australians and New Zealanders are dominantly of British stock and have somewhat greater interest in and familiarity with industrial management than those who control the capital and governmental policies of Latin America. The greater number of factories of Australia and New Zealand are concerned with the preparation of foods: flour and sugar milling, fruit preserving, meat packing, and butter and cheese manufacture. Others of long standing are the ore-reduction plants associated with the mining of gold, zinc, and other valuable minerals, also sawmills and plants turning out bulky wood products, such as furniture. During the First World War the shortage of shipping made it profitable to set up a variety of other manufactories, many of which languished in the postwar period because of their high production costs. Some have persisted, however, and Australia, particularly, entered the second great war of the century with several types of manufacture already in operation on a fairly large scale. These include blast furnaces and steel mills. near the coal fields of the east coast, textile mills in Victoria, clothing manufacture, and various types of machine and armament plants, some of them now greatly enlarged as a result of a second war emergency.

865. The Union of South Africa, of all the Southern Hemisphere centers of population, has developed least in manufacture. However, the need of equipping military forces has recently led to industrial expansion there also. Small and local industries have enlarged their capacities and widened their manufactural scope. South African coal and mineral ores make this possible.

WAR INDUSTRIES AND THE POSTWAR INDUSTRIAL PATTERNS OF THE WORLD

866. The distribution and the character of the world's leading centers of manufacture have resulted from a slow evolution through the operation of elements in the physical environment and economic factors which have previously been considered. In this evolution the factors of relative advantage for and experience in manufacture have expressed themselves in the comparative costs of the various classes of goods to the consumers and in the qualities of the goods. To some extent always these factors have been offset by the nationalistic objectives of governments made manifest through tariffs and other protective regulations. In the main, however, the strong forces have been good and cheap sources of fuel and power, abundant and skilled labor, available capital, and experienced management. Normally, these forces have been sufficient to overcome the disadvantages of transportation costs on raw materials from distant sources and on finished products to distant markets.

War, however, creates an entirely different situation, and total world war brings revolution rather than evolution to bear upon the industrial patterns of the world. Goods of almost every type are required in quantity regardless of cost. Many of the products of manufacture are destined to temporary and destructive rather than long-time and constructive uses. Old industries are abandoned or moved to new sites of less natural advantage for reasons of military safety. Less adaptable raw materials are substituted for better ones which come from vulnerable sources. New industries appear in regions which previously were undeveloped. In fact, the whole industrial pattern of the world is changed within the span of a few months. Which ones of the abandoned industries will reappear, and where,

which of the new ones will remain, and why, only the events of the future can decide. Undoubtedly the natural conditions favorable to manufacture and the usual economic forces will again exert themselves, and the old manufactural regions will resume something of their former character. Probably, however, the return will never be complete, and the patterns of the future will be in many details unlike those of either the past or the present.

CHAPTER 32: *Communications, Transportation, and Trade*

867. Function and Significance of Communications. All forms of communication are for the purpose of facilitating the movement of man, his ideas, or his goods from one place to another. As the telephone, telegraph, cable, and radio transport man's ideas, so ships, trains, motorcars, airplanes, and animals transport him and his goods. When a raw material has been converted by manufacturing processes into a finished product, it has been made more useful or more valuable through a change in *form*. When a commodity is moved from a place where it is not wanted to a place where it is needed, it has been made more useful or more valuable through a change in *place*. Just as manufacturing creates *form utility* in commodities, so transportation creates *place utility*. When raw cotton is converted into a useful and valuable garment, form utility has been added. However, there may be little demand for the garments at the place where they are manufactured but, on the other hand, a very active demand for them in other regions. By transporting the garments to the places where they are needed, there has been an increase in their value to society, an increased value that is every bit as real as that added by the manufacturing processes.

It has been said that the dominant economic fact of our modern industrial and scientific age is the development of cheap, fast, and efficient transportation. The economic structure of the nineteenth and twentieth centuries has been built upon cheap transportation. The Road, used here as including all lines of communication, is one of the most fundamental institutions of mankind. It is so necessary and so natural a part of human existence that we take it for granted. "Not only is the Road one of the great human institutions because it is fundamental to human existence, but also because its varied effect appears in every department of the state. It is the Road which determines the sites of many cities and the growth and nourishment of all. It is the Road which controls the development of strategics and fixes the sites of battles. It is the Road which gives its framework to all economic development. It is the Road which is the channel of all trade and, what is more important, of all ideas. In its most humble function it is a necessary guide without which progress from place to place would be a ceaseless experiment; it is a sustenance without which organized society would be impossible; thus, and with those other characters I have mentioned, the Road moves and controls all history.

"A road system, once established, develops at its points of concentration the nerve centers of the society it serves; and we remark that the rise and decline of a state are better measured by the condition of its communications—that is, of its roads—than by any other criterion."[1]

868. Effects of Efficient Transportation. The most obvious effect of efficient transportation is to make available to a community goods which are produced elsewhere. It is this creation of place utility in goods by means of transportation that permits the development of regional specialization in production. Unless goods could be readily moved from places of excess to regions of deficiency, each region would be compelled to produce all the kinds of things needed in just the right quantities—no more and no less than could be consumed at home. Where communications are adequately developed, however,

[1] Hilaire Belloc. "The Road." Harper & Brothers, New York, 1925.

there is no such inhibiting influence, and regions are permitted to specialize in those types of production which they are best fitted by natural endowment or cultural heritage to do and at the same time neglect those for which they are less well equipped. Without the development of adequate means of communication for facilitating the movement of goods and ideas, advanced stages of economic development are impossible. Indeed, there is a direct relationship between the adequacy of the communications of a region and its stage of economic development.

The development of large cities is dependent upon cheap and efficient transportation. In the prerailroad era large cities were located along navigable waterways. The development of inland metropolises waited upon the railroad. The concentration of large numbers of people in a restricted area, such as a city, makes necessary the deriving of a food supply, especially perishable foods, from beyond the immediate locality. The processing of goods, which is one of the primary functions of cities, requires the concentration of large amounts of raw materials and power and the distribution of the finished products to markets beyond. Urbanization, which epitomizes regional specialization and subdivision of labor, is dependent upon a flow of goods.

Cheap and efficient transportation tends to reduce the cost of goods to the consumer. This may be done through the encouragement it gives to large-scale production. It likewise gives purchasers the benefit of increased competition and so tends to hold prices down. The better diffusion of goods through transportation reduces waste from overproduction and stabilizes and equalizes prices.

Apart from the economic effects of improved transportation there are others which are social and political in character. To a large degree it determines the distribution pattern of population. Early settlements in this country were usually along navigable waterways. Highways and railways have made wider dispersion possible. Better transportation results in improved housing, food, and clothing, so that the whole standard of living is lifted. Leisure is increased, social contacts are broadened, and incentive to progress is strengthened. National unity is promoted through drawing the different parts of a large and diverse country closer together. By promoting regional specialization an efficient transportation system creates a greater need for national unity. By no means of least importance is the effects of transportation upon national defense.

869. The Urge to Trade. Commerce exists because of the desire of individuals and countries having different goods to exchange their surplus for the surplus of some other people. We live in an era of regional specialization and in a society so organized that such an exchange is an absolute necessity. Some parts of the world and some parts of the United States are dominantly pastoral, others agricultural or manufactural. Some agricultural regions specialize in a limited group of crops, and some manufactural regions in a restricted range of products. Probably the greatest factor making for increased productivity of the earth and its regions is that organization which permits different regions to specialize in the tasks that are best suited to the peculiarities of their physical equipment and congenial to the tastes and attitudes of their peoples, while at the same time making use of their special aptitudes.

Such differences in production, which are the bases of trade and therefore the prime reason for communication systems, arise from several causes among which are (*a*) differences in the people themselves, (*b*) differences in the physical characteristics of the various parts of the earth including the unequal distribution of natural resources, and (*c*) differences in the economic development of peoples or in their stage of civilization. Of these the first is perhaps the least important, for with the better development of communications and trade there is a tendency for racial differences and their commercial results to disappear. Native culture finds it difficult to persist in the face of competition offered by the imitations produced by machine manufacture. Still, the blankets and basketry of American Indians, the Oriental rugs of the peoples of western Asia, and the lacquer, porcelains, and

tapestries of the Chinese and Japanese are examples of kinds of surpluses entering into trade that have their origins, at least in part, in the characteristics and cultures of the peoples themselves.

More fundamental, however, as a basis of trade are the differences in the characteristics of the physical earth, including its natural resources. Between the tropics and the middle latitudes there is a large exchange of products based primarily upon differences in climate. Two out of the four top-ranking imports of the United States (crude rubber, cane sugar) are from the tropics. Manila hemp, coffee, jute, henequen, coconut products, palm oil, bananas, cacao, and tea are other items in our import list arriving from the frostless lands to the south. In our Latin American trade relations we have much closer ties with the tropical parts of that region, whose products are noncompetitive and therefore complementary to ours, than with the middle-latitude countries of southern South America, whose products are similar. California's large export of horticultural products to northern and eastern United States largely results from differences in climate. There are some who predict that this north-south trade based upon climatic contrasts is destined to be the trade of the future. Between humid lands and dry lands likewise there are natural bases for trade. Beyond the bounds of cultivation in many dry regions are the sheep and cattle ranches which send their animal products into the markets of the more populous humid lands.

Differences in relief or surface irregularity likewise give rise to contrasts in production, which result in trade. On the steep and rock-strewn slopes of mountains the tilling of crops is difficult so that such regions are more characteristically used for grazing, forestry, or mining. Between the agricultural plain and the less agricultural mountain there are fundamental reasons for an exchange of surpluses. Soil contrasts have a similar effect. Between regions well endowed with basic minerals and those either lacking or having a deficiency in those resources, there is the basis for a flow of goods. This may take the form of actual shipment of minerals in raw or semiprocessed state, such as the movement of Swedish iron ore to Germany and England, the shipment of British coal to the coal-poor Mediterranean lands, or the export of American petroleum to Japan. Or on the other hand, the presence of these basic minerals may lead to specialization in certain kinds of manufacturing and a consequent exchange of commodities between a nonmineralized nonmanufacturing region and one possessing the mineral resources and the manufacturing based upon them. The basic exchange between the mineral-poor River Plate countries of South America and Great Britain is between two regions fundamentally in contrast as regards basic minerals, which contrast is reflected in the kinds of surpluses of the two regions.

At the present time at least, contrasts in the kinds and stages of economic development of nations and regions seem to be the single most important basis for trade. This is reflected in the preponderance of east-west trade over that moving north-south. It should be recognized, however, that the basis of trade between two regions is more often than not the result of several causes rather than one. Thus the exchange between the United States and tropical Latin America results both from contrasts in climate and from differences in stage of economic development, and perhaps also from differences in the people themselves. The trade between Great Britain and India appears to involve all three reasons as well. The greatest trade is between regions and countries of most advanced economic development and where standards of living are highest.

870. Four Classes of Features Associated with Transportation. Transportation or communication involves four different classes or groups of features that are of geographic significance, *viz.*, (*a*) the things or commodities exchanged, (*b*) the vehicles or conveyances transporting the commodities (ships, trains, motor trucks, airplanes, beasts of burden, men), (*c*) the routes followed by these vehicles (sea lanes, railroad lines, land roads, air lanes, cables, telephone and telegraph lines), and (*d*) the terminal facilities along the routes.

The Commodities of Trade: Kinds and Magnitude

871. It should never be lost sight of that routes of trade, the carriers that move over these routes, and the terminals of these carriers all exist for the sake of the commodities that are in process of being exchanged. Not infrequently it is the trade routes and the trade centers that are given chief attention, but to do so neglects the basic fact that the goods that flow over the routes and pass through the terminals are of primary importance.

Unfortunately it is impossible to give a concise picture of the magnitude and kinds of goods comprising the trade of the world and its various parts. For the trade that crosses international boundary lines, or foreign trade, there are fairly adequate statistics, but for that larger movement that takes place within countries, domestic trade, information is difficult to obtain. In magnitude the foreign trade of the United States is only a fraction of its internal commerce. In a recent prewar year our foreign trade was nearly $5,500,000,000, whereas the domestic retail trade alone amounted to $42,000,000,000.

872. World Trade. In 1947 the foreign trade of the world was valued at about 96 billion dollars. Discounting the advance in prices this is not greatly different from the trade volume of the world in 1938, which indicates that in 1947 goods were moving in international trade at about the same rate as before the war and at a substantially higher rate than in 1946. Although hundreds of commodities comprised this trade, the bulk of it was made up of items of general consumption, for food, shelter, clothing, and means of production are the most important requisites of modern society. Foods, textile fibers, minerals, and manufactured goods comprise the four principal classes of commodities entering into trade. Among foods the cereals are most important, with wheat the outstanding single item in the Occident and rice in the Orient. Compared with the trade in these two cereals that involving rye, corn, oats, and barley is small. Another of the important food groups is meats and animal fats. Roughly 2,500,000,000 lb. of beef and its products and 2,000,000,000 lb. of pork and its products annually find their way into world trade. There are additional large quantities of mutton, canned meat, butter, cheese, fish, poultry, and eggs. Vegetable oils make up a third group, and fruits, nuts, vegetables, condiments, and beverages (tea, coffee, cacao) a fourth.

Among the textile fibers, used chiefly as raw materials in the manufacture of cloth, rope, twine, and bagging, are included cotton, wool, silk, jute, hemp, and sisal, together with many less important ones. Outstanding in the mineral group are such bulky ones as coal, petroleum, iron ore, lead, and zinc. In tonnage this group takes first rank. A large group designated as miscellaneous includes a host of items, among them such outstanding ones as rubber and timber.

Per Cent of World Trade by Continents in a Recent Prewar Year
(By value)

	Imports	*Exports*
North America	16.8	20.4
South America	4.6	7.4
Europe	56.7	47.6
Asia	13.4	16.3
Oceania	2.7	3.4
Australia	5.8	4.9

The striking feature of the preceding table showing per cent of world trade by continents, and of Fig. 434 showing distribution of foreign trade by countries, is the unusual concentration in Europe. In part, this reflects a similar concentration of population and of industrial development (Fig. 405). However, the fact that the continent is divided into a large number of relatively small but important countries naturally leads to much trade crossing international land boundary lines, which thereby becomes foreign commerce. On the other hand, the immense trade between different regions within a large political unit like the United States is domestic in character and consequently does not appear in the preceding table.

In the prewar era the greatest trading nations were concentrated around the North Atlantic

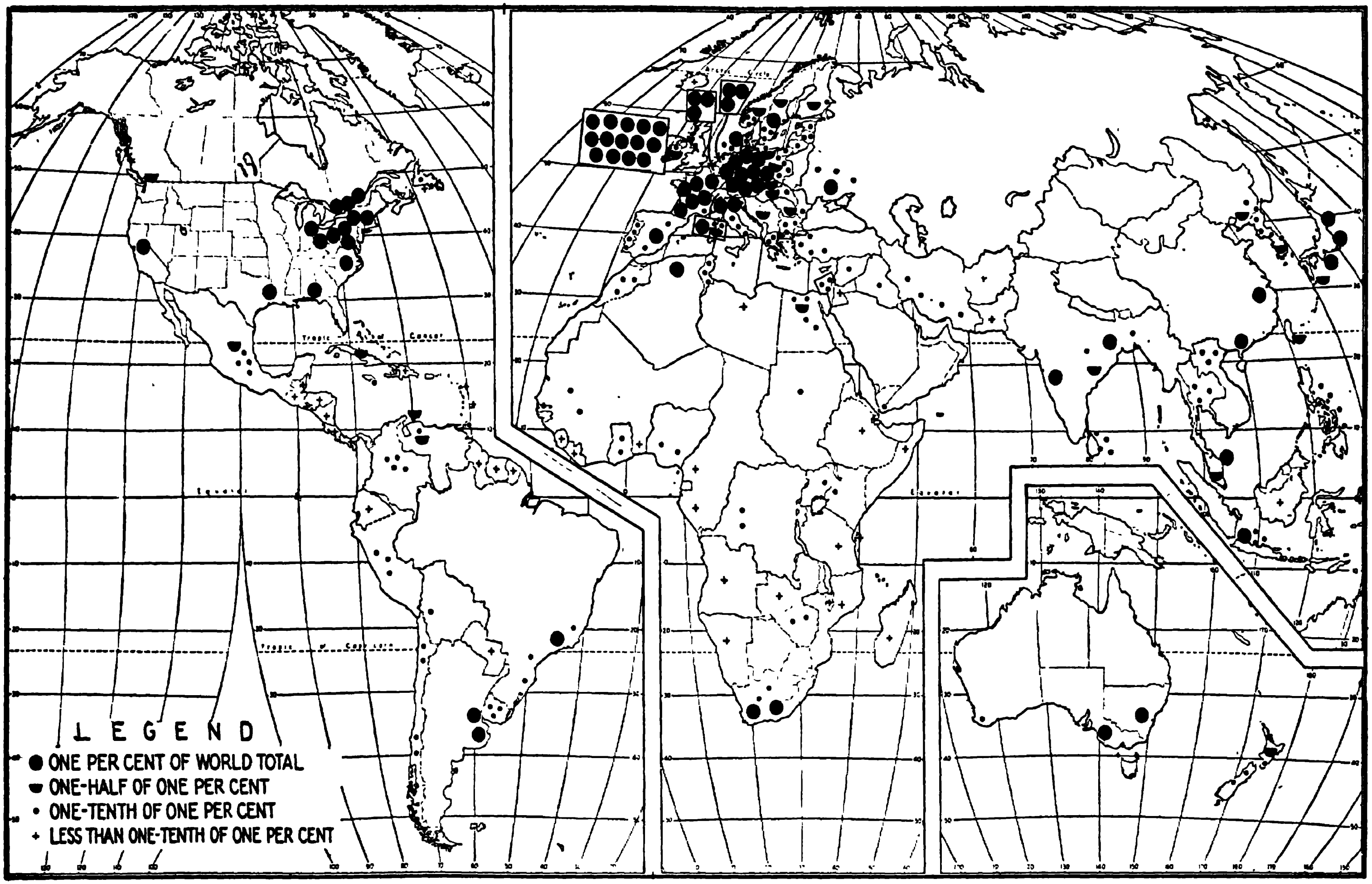


Fig. 434. Distribution of world trade in a prewar year by countries. The two great centers engaged in foreign trade are western Europe and the United States, both of which front upon the Atlantic Ocean. (*Modified from Jones, "Economic Geography."*)

Basin. Britain held first rank, followed in order by the United States, Germany, and France. In 1938 the Eastern Hemisphere exported almost three-quarters of the world total (Europe, 48.6 per cent; Asia, 16; Oceania and Australia, 7.8). Resulting from the war there have been numerous dislocations in foreign trade, many of which still prevail. Of foremost importance is the sharp decline in the exports of the Eastern Hemisphere, especially Europe, and a compensation for this export deficit by a notable increase in sales from the Western Hemisphere, chiefly the United States. During 1947 the United States supplied over one-third of the products in world commerce as contrasted with 14 per cent before the war. Great Britain and the United States are still the greatest traders, but their prewar positions have been reversed. Germany, of course, has disappeared from the list of traders as has Japan, and Canada has risen to third position with France fourth. It will be noted that for the European nations imports greatly exceed exports, which suggests that much of their buying is being financed by United States credits. By contrast, the United States in 1947 sold 2.7 times as much as it purchased. Such disequilibrium in the trade of the leading countries is abnormal and represents a condition which cannot prevail for long. It is still too early in the postwar period, however, to be able to see just what the more stable patterns of world trade will be.

Foreign Trade of Selected Nations, 1947
(In millions of American dollars)

	Exports	*Imports*
United States	15,338	5,733
United Kingdom	4,821	7,204
Canada	2,775	2,561
France	1,788	2,911
Belgium-Luxemburg	1,406	1,951
Argentina	1,588	1,308
India	962	864
Brazil	146	1,217
Sweden	894	1,437
Switzerland	763	1,126
Australia	988	737
The Netherlands	701	1,603

873. American Foreign Trade. Although the foreign trade of the United States is only a fraction of that country's much greater domestic trade, it is nevertheless a vital element in the prosperity of the nation. If overseas markets were to shrink markedly, the economic prosperity of this country would be seriously endangered. In the postwar period the United States has become the ranking foreign-trade nation, but unfortunately this is largely in expanded exports, made possible by our loans. Only as our customer nations are able to revive and reconstruct their economies so that they can export goods, which we in turn will buy, will American foreign trade be on a secure footing. If the United States is to continue to sell abroad, it must at the same time be ready and willing to buy. Considering the country as a whole, and not special groups of producers, the net effect of protective tariffs upon all groups in a country is adverse. Tariffs imposed primarily for raising revenue or those necessary to keep alive industries essential for defense are in a different class.

The diversity of the foreign trade of the United States is indicated by the following table showing the leading exports and imports in 1946. Exports are heavily weighted in favor of manu-

Leading American Exports, 1946 (Ranked according to value)	*Leading American Imports, 1946* (Ranked according to value)
1. Grains and grain preparations	1. Raw wool
2. Machinery	2. Paper manufactures
3. Raw cotton	3. Rubber
4. Steel-mill products	4. Sugar
5. Petroleum and petroleum products	5. Precious stones
6. Cotton textiles	6. Paper pulp
7. Meat	7. Petroleum and petroleum products
8. Coal	8. Silk and silk manufactures
9. Dairy products	

factured goods, 78 per cent being a combination of finished manufactures, semimanufactures, and processed foodstuffs. Imports, on the other hand, are less heavily weighted in favor of any one class of goods, although crude materials and crude foodstuffs comprise 53 per cent of the total. This is exactly the reverse of the export situation. The principal class of imports

The Nature of the Foreign Trade of the United States in 1946, Per Cent

(Figures in parentheses are for 1947)

	Exports	*Imports*
Crude materials	14.9 (11)	35.8
Crude foodstuffs	6.9 (16.6)	16.9
Manufactured foodstuffs	16.0 (16.6)	10.4
Semimanufactures	9.4 (12)	19.3
Finished manufactures	52.8 (60)	17.6

is crude materials for use in American factories, amounting to 36 per cent of the total. Finished manufactures, by contrast, comprise only 18 per cent. It appears, therefore, although American foreign trade is highly diversified, that there is a high preponderance of processed goods in our sales and a slight prep nderance of crude materials in our purchases. All these are evidence of a highly industrialized country, but at the same time one which, unlike Britain, has important surpluses of certain foods and industrial raw materials as well.

Foreign Trade of the United States, 1946, by Continents, and Selected Countries

(In millions of dollars)

	Exports	*Imports*
North America	2,544	1,647
Canada	1,442	882
Mexico	505	233
Central America	168	83
The Caribbean and Bermuda	396	416
South America	1,152	1,095
Argentina	193	194
Brazil	356	408
Chile	77	84
Uruguay	48	48
Peru	63	36
Venezuela	212	120
Colombia	145	157
Europe	4,098	796
United Kingdom	856	156
Belgium and Luxemburg	279	77
France	712	63
Soviet Russia	358	101
Italy	371	69
Sweden	206	47
Netherlands	222	23
Poland	183	
Switzerland	108	98
Czechoslovakia	107	19
Asia	1,343	908
China	466	93
Japan	102	110
Netherlands Indies	73	34
India	181	238
Philippines	297	40
Malaya	15	127
Australia and Oceania	117	183
Africa	488	305

874. *Trade Regions.* Both in the prewar and the postwar periods, Europe was the best customer of the United States. In 1946 that continent took 42 per cent of our total exports. By contrast, however, it supplies only 16 per cent of American imports and its purchases were valued at only one-fifth of its sales. Such an unbalanced trade is wholly abnormal and cannot be of long duration. Within Europe, Great Britain and France are much the largest buyers of American goods, while Great Britain, Soviet Russia, and Switzerland are our principal sources of imports. Next to Europe our greatest trading area is North America, and among the nations Canada, Mexico, and Cuba rank in that order. With no other country do we trade so much as with Canada. Geographical proximity, without doubt, is a large factor in this trade. South America and Asia are about on a par in terms of total value of trade with the United States.

Routes of Transport and Their Carriers

875. Types of Trade Routes. The world's trade routes may be classified into three general types: land, water, and air. At least one fundamental difference distinguishes most land routes from those in the air and on the water, *viz.*, in the two latter no trace is left by the vehicle after it passes. A ship slips through the water, and in a few moments all record of its passage has been obliterated. The same is true of air transport. On the other hand, the land almost invariably preserves traces of routes followed. As a consequence of this difference, it is to be expected that air and water routes are not nearly so definite in location as are those of the land. The direction and course of any route are determined, first of all, by the points that are to be connected and, second, by the obstacles that interpose themselves between these points.

But although routes may, for convenience of

discussion, be divided into the three classes named above, it should not be lost sight of that they are integrally related. In modern trade a water route may be a continuation of a land route and vice versa, and the coastline is simply a point of transshipment along the route, made necessary by a change in mode of transportation. Thus wheat moving to New York City reaches Duluth by rail, is there shifted to lake steamer, which may carry it to Buffalo, from which terminal it is again transshipped to rail or canal barge, which sets it down in New York.

LAND ROUTES AND THEIR CARRIERS

876. The human body is the most universal as well as the most primitive means of land transport, and human portage still prevails in many parts of the world. Animals, too, such as the horse, camel, donkey, and ox, serve in the same capacity and, because of their greater strength, are able to carry heavier loads and often with greater speed than can man. But it is usually easier to drag a burden than to carry it, and this fact very early led to such mechanical inventions as the rollers of the Assyrians, and later the wheel, upon the axle of which was built the cart. The exact place and time of origin of the wheeled vehicle is not known, but it goes back into prehistoric times. Its invention marks one of the greatest forward strides in the evolution of transport. Most of our modern means of land transport, the automobile and the train, are but modifications of the original wheeled cart, mechanically powered so as to provide greater speed and pulling strength as compared with the human- or animal-drawn vehicle.

Land routes and their carriers changed more rapidly during the nineteenth century than during the entire period of world history up to that time. Until the development of the portable steam engine, land travel the world over had been by human carriers on foot, pack animals, ox- or horse-drawn wagon, or by river and canal. All these were slow, and the amount of goods that could be carried was relatively small. With the development of the railroad after about 1840, land transportation was revolutionized in some parts of the earth. However the earlier primitive means of travel have by no means disappeared. Over large areas of the earth, particularly those less advanced in material civilization, these forms still are the standard ones (Fig. 435). Even in the most advanced countries their least accessible and thinly populated parts are still served by the more primitive transportation facilities.

Fig. 435. A common form of transportation in Japan. The roads in Japan are narrow and frequently winding but, on the other hand, they are surfaced and all-weather in character. (*Three Lions.*)

1. *Highways and Motor Vehicles*

877. The Road. Of all land routes, the *road*, including everything from the humblest path to the modern concrete highway, is the most ancient as well as the most universal. Ancient Rome recognized the strategic value of roads in facilitating the quick shifting of troops to any part of the Empire, and as a result highways were constructed, not only in Italy, but over the Alps into the basins of the Danube and the Rhine, to the center of Spain, and even in England. Other ancient peoples such as the Chinese and the Incas built paved roads, but it

remained for the Romans first to organize separate roads into a system or network, all parts of which fed into one another (Fig. 435). Not all peoples construct such permanent highways. Among the dunes of the Sahara are paths worn by camel trains of caravans, while porters' feet have left imprints upon the jungle soils and vegetation of the Congo. Every human establishment, no matter how insignificant, becomes a focus of roads, and the greater its attraction, the greater the multiplication of trails leading to it.

878. Functions of Roads. Most of the roads of the earth grew out of the needs for local transportation. Only to a limited extent were the public roads expected to function in long-distance movement of people or goods. In the United States the early public roads were for the purpose of providing connections between farmsteads and the market towns where the farmers traded. Only a few, such as the eastern post roads and the Cumberland Road, were planned with long-distance transportation in mind. And, although the development of the motorcar within the past four decades has had a notable effect upon trunk-line highways, it is still true that of the 3 million miles of public roads in this country, roughly 1.7 million miles are ordinary unsurfaced dirt roads serving chiefly the rural population. Surfaced roads of all kinds reach a total of 1,300,000 miles, of which only 191,000 miles have a hard surface of a high type. The latter are chiefly the trunk-line routes. To a large degree the highway "fills with a finer weave the coarse meshes of the railway net."

879. Motorcars and Their Services. The rapid expansion of surfaced highways during the past few decades has been a by-product of the phenomenal increase in the use of motor vehicles. In the preautomobile era it was Europe that set the world standard for good roads. But when Americans began to purchase automobiles in numbers they shortly demanded good roads, for now they had a vehicle that was meant for speed and that could travel long distances. The effect upon road building and improvement in America was startling. At the present time over one billion dollars are invested each year in the construction and maintenance of roads. Other parts of the world also have felt the effect of the automobile upon road building. The cost of rolling stock and right-of-way maintenance are much less for bus and truck than for railroads, and at the same time there is a far greater flexibility of usage. Countries with little capital therefore have elected to improve their transportation by providing themselves with better roads and motorbusses and trucks rather than by investing in railroads. Such a development has been striking in regions like Poland, Finland, the Baltic States, and China.

In 1910 it is estimated there were only 600,000 motor vehicles in existence. By 1920 this had increased to 11 million, in 1930 to 35 million, and in 1941 to over 45 million. What the world total was in 1946 is not known, although in the United States there were 1.8 million more than in 1941. Over 70 per cent of the world's motor vehicles are concentrated in the United States. Northwestern Europe is the region of next highest concentration. Motor transport has won its present position partly by displacing horse-drawn vehicles, partly by capturing rail traffic, and partly by increasing the total amount of traffic.

Highway motor transport is very diversified in form for it is conspicuous in both passenger and freight service, in local and intercity movements, and in private and public service. Counting all these different forms, more traffic moves by highway than by all other means of transportation combined. It is in the passenger field that the motor vehicle has contributed most. Largely the passenger miles accumulated are by private passenger cars used for pleasure and not for business. Revenue passenger motor service takes the form of taxicabs and busses operating both within and between cities. To a considerable degree city busses supplement surface trams and subways and in many cities have resulted in the abandonment of surface street cars. Intercity motor bus routes in the United States exceed the line mileage of railroads, and intercity busses carry upward of the number of passengers carried by the railroads.

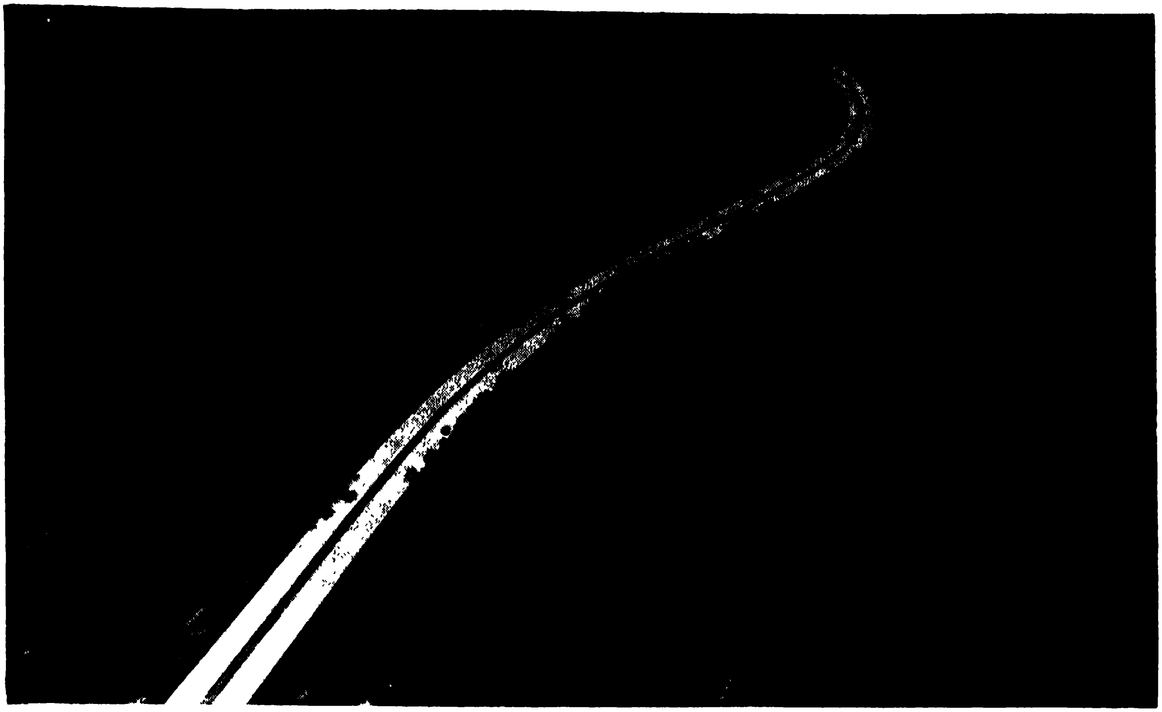


Fig. 436*A*. Aerial view of the famous Pennsylvania Turnpike, one of this country's most modern highways. (*Pennsylvania Turnpike Commission.*)

Fig. 436*B*. Aerial view of the Blue Mountain Interchange along the Pennsylvania Turnpike. (*Pennsylvania Turnpike Commission.*)

Because of the longer hauls, however, the railroad passenger mileage is about three times as great. The advantage of the motorbus over the railroad is associated with two factors: (*a*) the carrying unit is small and less expensive, and (*b*) it is not confined to a fixed roadway. The first permits of service in small loads over public highways with numerous and convenient stops for pickup and discharge of passengers. The bus serves best where traffic is light and where speed is not so important. Where traffic is heavy and speed is essential, it must yield to the railway.

Motor trucking is predominantly short-haul transportation, although the length of the haul has been increasing. In 1940, over two-fifths of the truck miles on rural roads did not cross county lines. On trunk highways the intercity trucking is largely intrastate in character, only one-fifth of the total ton miles representing interstate freight movement. Intercity trucking also is concerned chiefly with high-class freight, often of the miscellaneous package class. The advantages of motor trucking over rail are related to such items as faster service, store-door pickup and delivery, cheaper total cost, cheaper packing, and less damage to freight. In the long-distance movement of bulk freight, railroads have a decided advantage. Railroads are making an increasing use of trucks for pickup and delivery service, for interline transfers, for reaching off-track stations, and for handling less than carload lots between cities.

880. Road Mileage, Density of Road Net, and Pattern of Road Distribution. The United States with its 3 million miles of roads suitable for motor traffic has 40 per cent more than its nearest rival, Soviet Russia. After Russia there follow in order Japan, Australia, Canada, France, Germany, and the United Kingdom. The density of the road net is highest in Japan, followed by Great Britain, Denmark, France, Ireland, and Belgium. The two *large* centers of high road density are western Europe and eastern United States, regions with large populations and relatively high standards of living. In these regions there is usually over 1 mile of road for each square mile of territory, and in parts it is much denser. Of surfaced roads in the United States there is about 1 mile to each 4 square miles of land area, but the ratio is only 1 to 25 for roads having a high type of hard surfacing (Fig. 436). The highest densities are in the northern and eastern region of the country, extending from northern Illinois to southern New England.

881. Road Patterns. Road arrangement, or pattern, is related to both physical and historical conditions. In general roads should, as nearly as possible, represent the shortest line between two points, but often they deviate from this straight-line route because of surface features, river crossings, swamps, and the like. In most sections of Europe and North America the easiest routes of travel were discovered by the earliest inhabitants, so that the main thoroughfares have been the principal arteries of travel since the regions were first inhabited. In the early settled eastern and southern parts of this country, roads tend to radiate from early settlements and follow relatively direct routes to other settlements except as they are deflected by surface features or drainage conditions. In those parts of the country settled after the Ordinance of 1785, which imposed the rectangular square-mile system of sections, townships, and ranges oriented north-south and east-west, the road pattern is distinctive (Fig. 437, Appendix C). Here the layout is predominantly rectangular, in the form of a checker-board with 1-mile intervals. Some roads that antedate the survey may cut across this pattern, others deviate from it in places because of physical conditions. New paved highways pay less attention to the rectangular land survey and take their courses so as to give the shortest distances.

2. *Railroads and Their Carriers*

882. Characteristics of Railroads. As the road is very ancient, so the railroad is a relatively modern type of land route, not having been in use much more than a century. The first railroad was built in England in 1825, and it has followed the expansion of occidental civilization into the four corners of the earth. It is a product of the Industrial Revolution, while at the same

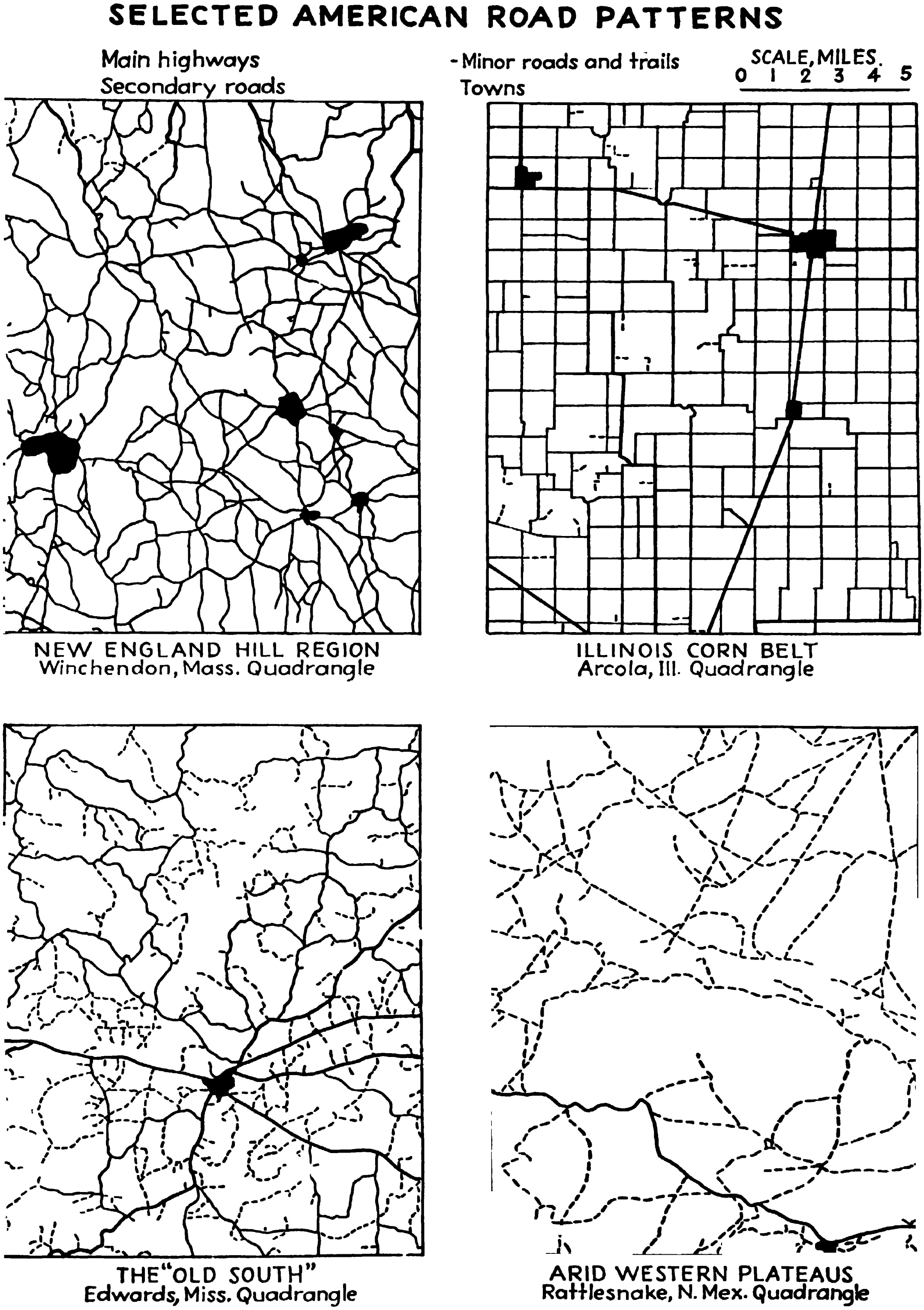

SELECTED AMERICAN ROAD PATTERNS
Main highways
Secondary roads
Minor roads and trails
Towns
SCALE, MILES
0 1 2 3 4 5
NEW ENGLAND HILL REGION
Winchendon, Mass. Quadrangle
ILLINOIS CORN BELT
Arcola, Ill. Quadrangle
THE "OLD SOUTH"
Edwards, Miss. Quadrangle
ARID WESTERN PLATEAUS
Rattlesnake, N. Mex. Quadrangle

Fig. 437

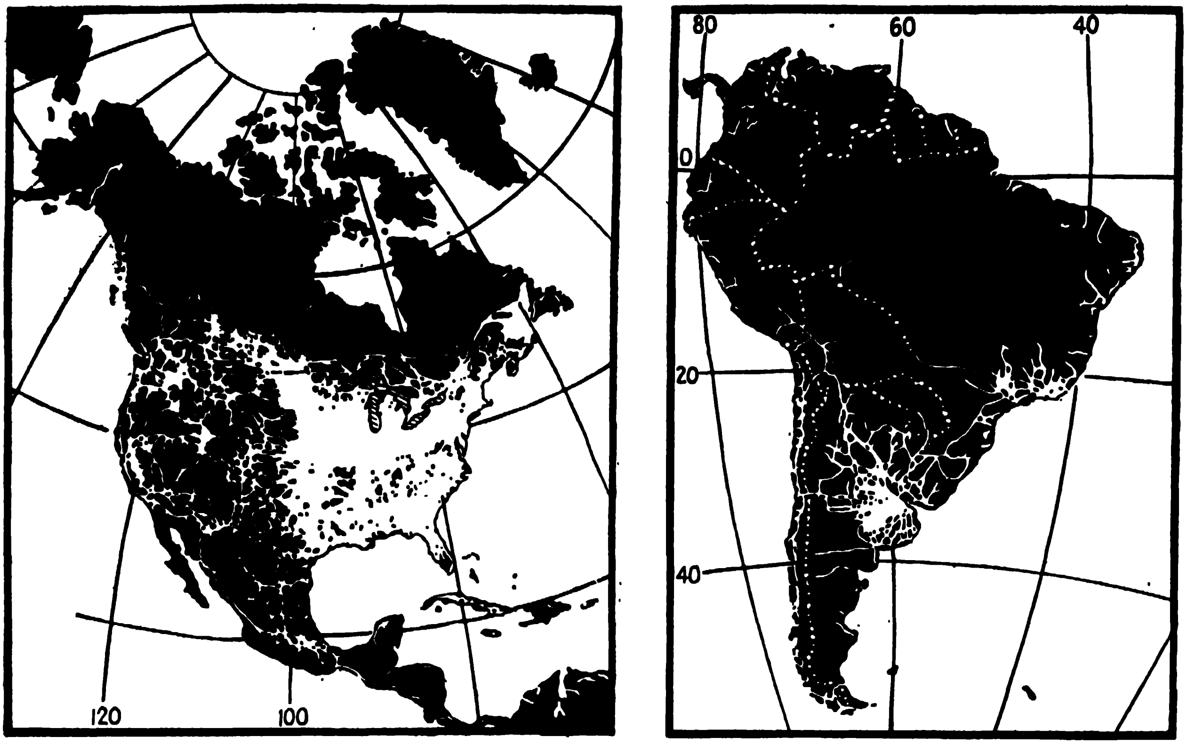


Fig. 438. Density and patterns of rail nets in North and South America. Strips shown in white are not more than 10 miles from a railroad. (*From Jefferson, "Exercises in Human Geography."*)

time it has made a complex industrial-commercial civilization possible. The course taken by a rail line is often quite different from that of a road. A train cannot negotiate steep grades as can a motor vehicle, so that rail lines are obliged to follow rather closely the major relief features. On the other hand, in the construction of a railroad bed use is made of cuts, fills, tunnels, and bridges in order to keep low grades so that the rail line is less influenced by minor features of the terrain. Because of the high cost of roadbed construction and of the rolling stock, the railway is a paying investment only when distance and length of haul can compensate for these handicaps. Its capacity for hauling large loads long distances at a relatively high rate of speed are the principal points of advantage which urged the rapid expansion of the world's railway mileage. Unlike waterways, collections and deliveries are not restricted to main lines, for by means of secondary lines and spur tracks small towns off main lines, and even individual factories, may have connections with the markets of the country and the world.

883. Expansion of Railroads and Their Present Distribution. Rail building followed closely the spread of western civilization, and the present-day pattern of world distribution closely coincides with that of machine civilization (Figs. 438 and 441). For the entire earth there are in the neighborhood of 750,000 miles of railroad of which nearly 320,000 miles are in North America, 67,000 in South America, including Central America and the West Indies, 250,000 in Europe, 84,000 in Asia, 31,000 in Oceania, and 21,500 in Africa. Western Europe and eastern North America are the two conspicuous centers with a large railroad mileage and closely spaced rail net. In both regions there are few areas that are more than 10 miles from a line. In England, Belgium, northern France, southwestern Germany, and portions of the American Atlantic Seaboard states, most areas are even within a

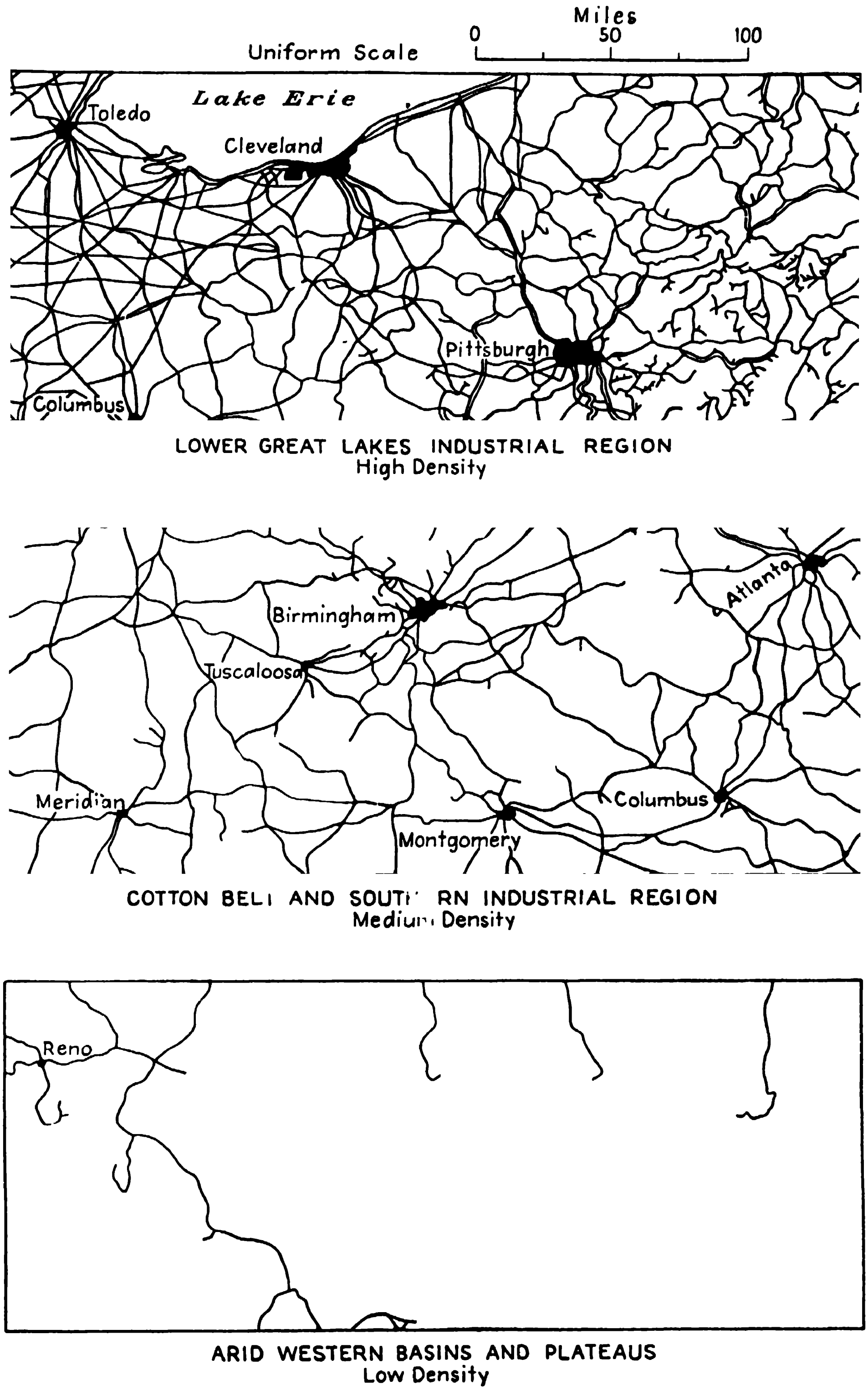


Fig. 439. Comparative densities and patterns of rail nets in three contrasting sections of the United States.

mile or two of rail lines. The railroad is a distinguishing feature of Euro-American culture, and its distribution is a good indicator of the spread and intensity of that culture.

884. *North American Railroads.* Only rail transportation could have made the resources of the immense spaces westward from the Appalachian barrier quickly available, and so it was that the rails marched westward with the American frontier. There was a close paralleling of railway building with the settlement and development of the land. The first lines were built to supplement waterways, but eventually they came to dominate transportation back from the seaboards. At present there are slightly under 250,000 miles of rail in the United States, which is approximately one-third of the trackage of the entire world. This immense length of rail line, like America's great length of highways, pipe lines, telephone lines, and her first rank in number of automobiles, reflects not only the country's prosperity, but also its great handicap of excessive space. Coal lies 1,000 miles from the ore, lumber is produced 2,500 miles from the principal markets, food is grown 1,000 miles and more away from the center of consumption. Our magnificent transportation facilities reflect the means by which the handicap of great distances is overcome.

885. *Density of Rail Net and Patterns of Distribution.* For different sections of the United States and Canada the *density* of the rail net varies greatly. In the poorly populated grazing regions of the western high plains and the intermontane plateaus there is only 1 mile of railroad for each 45 square miles of land. In the highly industralized northeastern part of the country from southern New England to Illinois the comparable figure is 1 mile for each 4.6 square miles, or ten times that density. Over the Middle West and the "old" South the ratio is 1 to 10. There is a remarkable thinning out of the rail net west of the 20-in. rainfall line, where agriculture is relatively unimportant and industries little developed (Fig. 439).

Over eastern United States the *pattern* of rail lines is that of a closely woven net. Within the general net there are a number of focal points toward which there is a general convergence of lines. Chief among these are Chicago and Winnipeg. In both cases natural barriers or unproductive land tend to direct rail lines toward these cities. The Great Lakes and the unproductive cutover land around the Upper Lakes prevent American rail lines from taking the shortest route eastward and force them southward through Chicago at the southern end of the barrier. Winnipeg likewise has a lake barrier and unproductive land on the north, which tend to direct rail traffic through that center. Atlanta at the southern end of the Blue Ridge barrier shows a similar pattern. Great ports such as Montreal, New York, and San Francisco are important focal points for local rail nets. Such a natural gateway as the Mohawk Valley across the eastern highlands is a convergence point for several rail lines (Fig. 440).

West of the 20-in. rainfall line the rail net disappears, and from there westward to the Pacific Coast states the single strands of the 10 great transcontinental lines with their few feeders are conspicuous. In this section passenger traffic is relatively more important than in eastern United States and freight less so, for the bulk of the intercoastal freight goes by boat via the Panamá Canal. Canadian rail lines are crowded close to the southern margins of the country by the unproductive nature of much of northern Canada. One rail line runs northward from the main Canadian National Railway in the wheat region across 510 miles of forest and swamp to Fort Churchill on Hudson Bay. This was built by the government with the idea of facilitating the export of wheat to Britain.

886. *European Railroads.* Whereas in North America railroad building was contemporaneous with the settlement of the country, in Europe it followed the settlement. This contrast is reflected in the rail patterns of the two regions, that of Europe being much more perfectly radial with respect to major trade centers (Fig. 441). Such great cities as London, Vienna, Paris, Berlin, Munich, and Moscow were already in existence at the beginning of

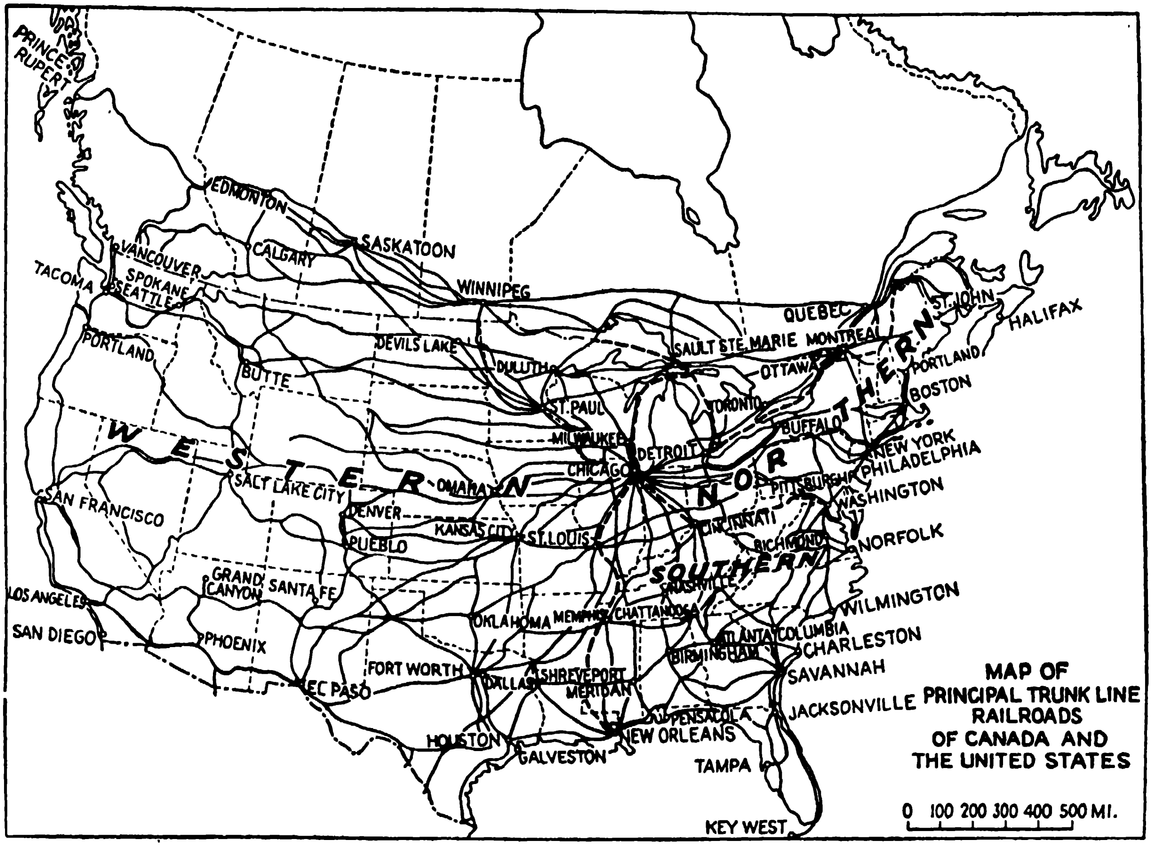


Fig. 440

the railroad era so that the rail lines were built with respect to these centers and the resulting patterns were definitely shaped by them.

This radial pattern in Europe has been fostered by another consideration, *viz.*, that of military effectiveness. Europe, made up of numerous independent countries of small size with the problem of national defense a major item, has a series of national railway systems, each system being a unit by itself. Less attention has been paid to the development of a unit system for the continent as a whole, involving international connections and transcontinental lines. Every effort was made to link the capital city and other strategic centers with the international boundaries so that troop movements to the borders could be facilitated in times of national danger. Many of Europe's railroads have been built with military rather than commercial use as the chief consideration.

The major transcontinental rail lines in Europe are the Paris-Berlin-Moscow route, the Paris-Milan-Brindisi route, and the Berlin-Vienna-Istanbul route. All these can be thought of as including London, although there is an obvious break at the English Channel. Relief characteristics of Europe are on the whole favorable to the development of rail lines, in spite of its numerous highlands. Through the highland rim of Bohemia the Elbe River has cut a famous gateway, the Saxon or Elbe Gate, that allows easy access from northwestern Europe to the Danube countries. At the western end of the Transylvanian Alps the Danube has cut the equally famous Iron Gate, which is an easy pass between central and southeastern Europe. By way of the Rhône-Saône depression western Europe finds easy access to the Mediterranean, while the lofty Alps are crossed by a series of low passes with easy approaches. Rail-

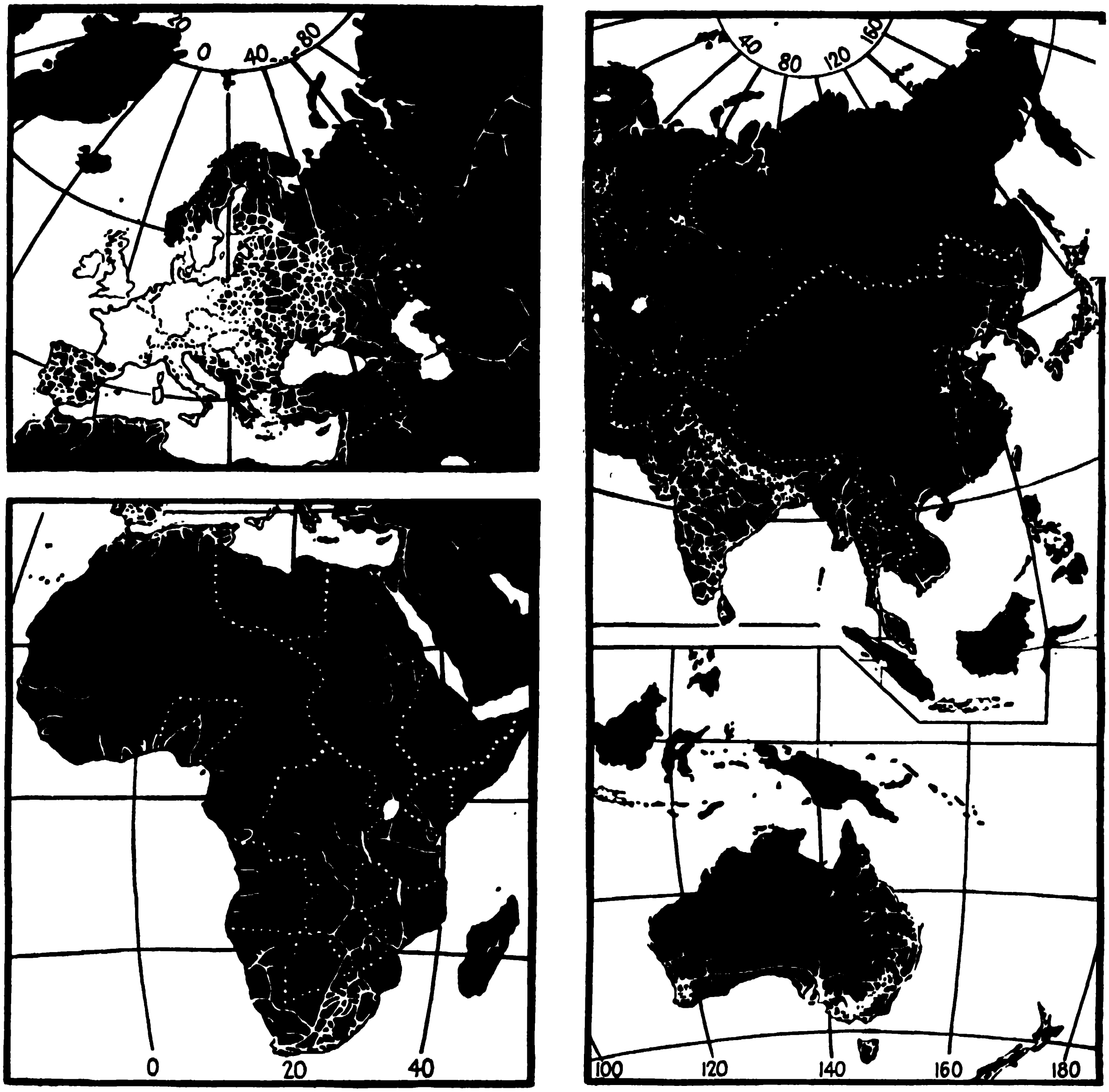


Fig. 441. Density and patterns of rail nets in the Old World. (*From Jefferson, "Exercises in Human Geography."*)

road ferries provide continuous rail routes between the Scandinavian countries and the German and Danish ports.

There are marked contrasts in the densities of the rail net in different parts of Europe. The highest densities per unit area for the entire world are found in western Europe. Belgium leads with 1 mile for each 3.9 square miles, but 11 other countries have densities greater than that of the United States. In southern and eastern Europe and in Scandinavia, regions of fewer people and less industrialization, the density is much lower than in western Europe.

887. *Railroads on the Other Continents.* The life of Asia is concentrated along its eastern and southeastern margins, and its chief railroad mileage is there as well. India has by far the largest amount of track, followed in turn by Japan and China. The rail net however is densest in Japan, which has a length of line per 1,000 square miles just slightly higher than that for the United States. Each of the national rail-

way systems in Asia is a unit within itself and is without connection with the others. Dry and high central Asia is largely without rail lines, the only significant ones being those built by the Russians into Russian Turkistan. Across Siberia reaches the long thin line of the Trans-Siberian connecting Vladivostok on the Pacific with European Russia.

African railroads are for the most part single short lines extending back at right angles from the coast for a greater or shorter distance into the interior. Between these isolated lines there are no connections, for the sea is the highway. Only in French Mediterranean Africa and in British South Africa are there any semblances of what could be called rail nets. The most notable route of the continent is that designated as the Cape-to-Cairo route, with railroads providing the means of transport over two-thirds of the length and boats and motorcars the remainder.

In Australia, the railroads follow the concentration of population and economic life along the eastern and southern margins. Genuine rail nets occur only in the southeast and the southwest. The dry deep interior is without through railroads. A number of short lines extend back at right angles from the east and south coasts into the inland semiarid sheep, cattle, and wheat country. These end abruptly on the edge of the desert where the grazing industry is limited by drought. A long, thin transcontinental southern line with few feeders

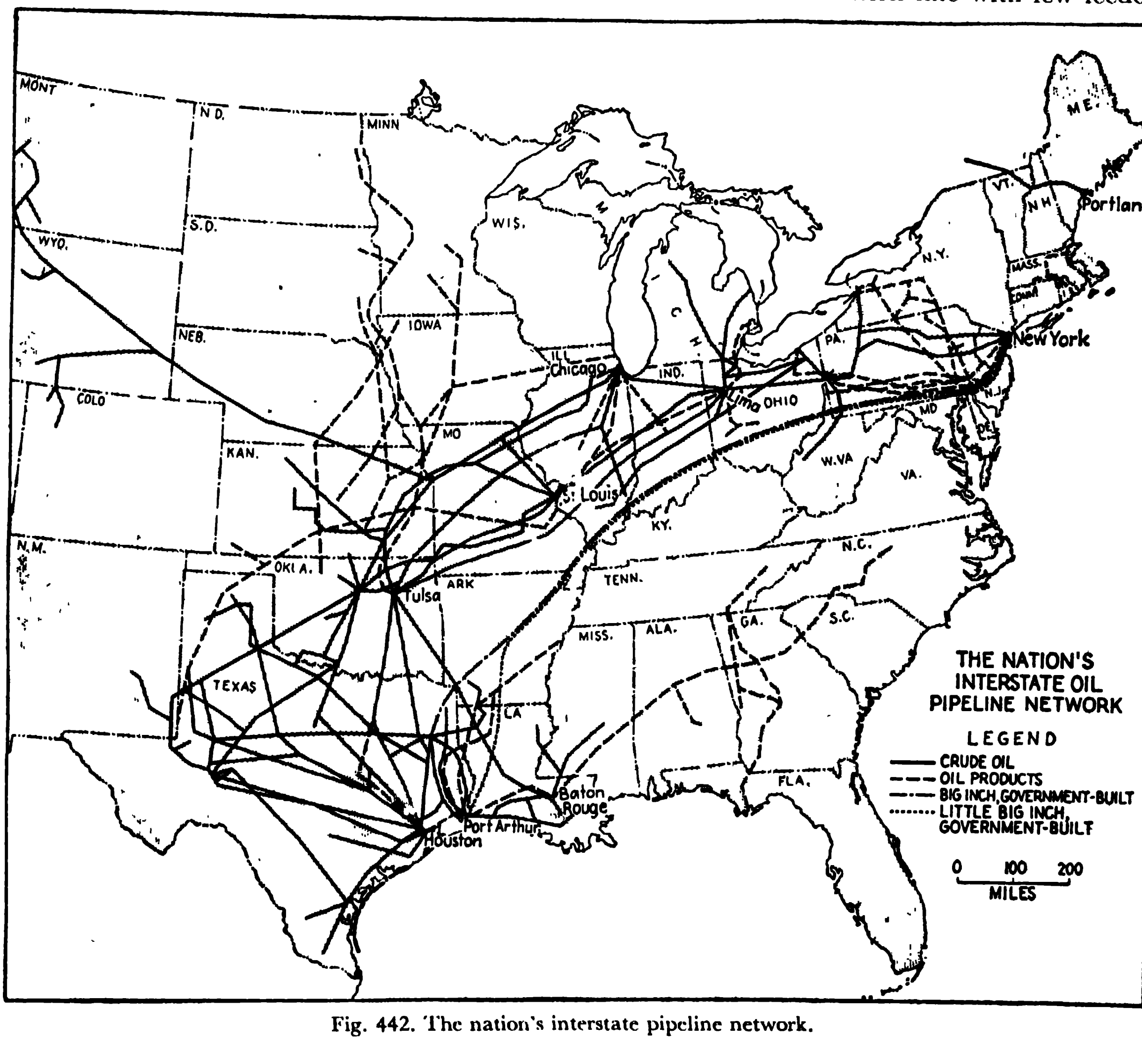


Fig. 442. The nation's interstate pipeline network.

connects the humid regions of the southeast and southwest.

Throughout most of tropical South America railroads are largely absent, the few that do exist being short isolated lines at right angles to the seacoast. In this part of South America the sea is almost the only highway connecting the principal centers of development, which are along the margins of the continent. The intervening lands are barrier areas rather than connections. Around the estuary of the River Plate in Argentina and Uruguay and in the coffee region of Brazil are the greatest areas of rail development. On the flat Argentine Pampa a fanlike pattern of rail lines, with its principal focus at Buenos Aires, is very conspicuous. West of the Andes a single longitudinal rail line extends from southern Chile to Peru and is connected by numerous laterals with the seaboard. Connection is made between the Argentine rail net and the Pacific Coast in Chile and Peru by three trans-Andean lines.

888. Pipe Lines. Fluid commodities, almost solely water, crude oil and gasoline, are the only ones moving by pipe-line transportation. Before the Second World War nearly three-quarters of the crude oil received at refineries was transported by pipe lines (Fig. 442). Because of the very widespread character of gasoline consumption, the percentage of that freight moving by pipe was very much less. Pipe-line transport of crude oil is more economical than any other overland type, being only one-quarter to one-half the rail rate. It is more expensive than movement by tanker, however. The operation of a pipe line is simple, and maintenance costs are low. The right-of-way expense is also low for the pipes are buried and the route is in rural areas for the most part.

WATER TRANSPORTATION AND THE MERCHANT MARINE

889. Advantages and Disadvantages of Water Transportation. The outstanding advantage of water transportation is the relatively small amount of power necessary to move bulky, heavy loads, provided that the speed of movement required is low. The capital and maintenance costs are also lower on waterways and their carriers. The net result is to make transportation by water unusually cheap. Thus, the cost of shipping iron ore nearly 1,000 miles from the western end of Lake Superior to the Lake Erie ports is less than the charge on rail shipment of this freight from Cleveland to the smelters in western Pennsylvania, a distance somewhat more than one-tenth as great. More freight can be moved by a single tow of barges propelled by one ordinary tug than can be moved by several freight trains. The cost of transportation on rivers and canals is higher than on oceans or on the American Great Lakes, but considerably lower than railroad charges. It should be borne in mind, however, that on artificial waterways improved and maintained by the government at public expense, the apparent low costs of water transport are not true costs.

The disadvantages of water transport are associated with the slower speeds maintained by boats and the inability of waterways to reach most parts of any trade region. At high speeds the friction of the water is excessive, and fuel costs rise exhorbitantly. Rivers are usually winding, and on canals the locks greatly reduce the movement of boats. In the higher latitudes with severe winters, inland waterways are closed by ice during several months of the year.

890. Inland Navigation. Rivers, canals, and lakes as routes of transportation have already been touched upon in Chap. 22. The principal handicap of rivers in general is that their courses are fixed and therefore the river trade route lacks the flexibility of a land or ocean route (Fig. 443). The course of a river can be altered only to a minor degree. It has often been pointed out that the Mississippi would be much more useful as a trade route if its course were east-west, which is the direction of our principal trade movement, rather than north-south. In densely populated industrial regions such as western Europe, rivers and canals are used to a much greater degree than they are in the United States. This probably reflects the need for every possible trade route that can be developed.

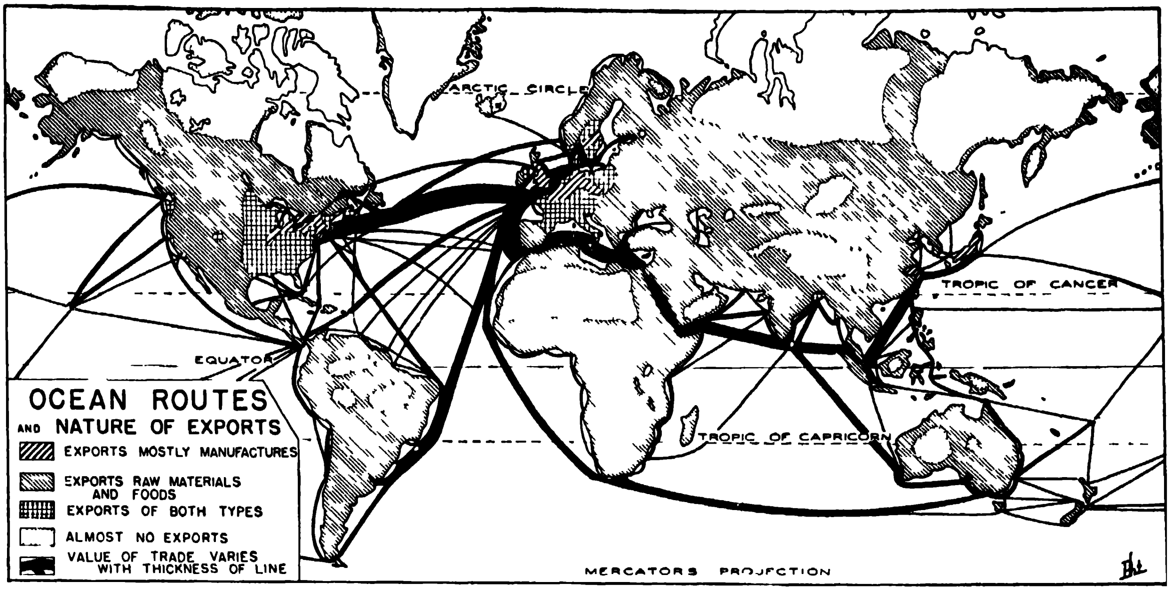


Fig. 447. (*From Klimm, Starkey and Hall, "Introductory Economic Geography," by permission of Harcourt, Brace and Company, Inc.*

Mediterranean Sea, Suez Canal, and the Red Sea. Its importance dates from 1869, with the opening of the Suez Canal. Unlike the North Atlantic route this one throughout much of its course follows relatively constricted waterways, which jeopardizes its safety in time of war. It is of principal importance to the European countries, particularly Great Britain, for it is the short route connecting them with their rich colonies and members of the Commonwealth in the Far East and the Pacific. In the Second World War one of the chief objectives of the Axis powers was the Suez Canal and the halting of the flow of goods and men through it to and from England. The frequency of ports along this route provides excellent opportunities for trade of the short-haul type.

896. Other Routes. *The South African route* connects the same regions as the Mediterranean route so that it in reality is an alternate to the latter. It is 4,000 miles farther from Liverpool to Calcutta by way of South Africa than by Suez, but many ships take the longer route to avoid the canal tolls.

897. *The South American–East Coast route* connects both sides of the North Atlantic with eastern South America. Because Brazil projects so far eastward into the Atlantic, American ships traveling to eastern South America are forced to make nearly as long a trip as those from western Europe. Under normal conditions the exchange of eastern South America is heavier with Europe than with the United States, with the products of farm, plantation, and range moving north to Europe and manufactured goods south to South America.

At the *Panamá Canal* are focused routes (*a*) between the east and west coasts of the United States, (*b*) between either side of the North Atlantic and the west coast of South America, and (*c*) between eastern United States and eastern Asia and Australia. The opening of the canal has eliminated the long trip around Cape Horn together with the dangers associated with navigating those waters. Greatest benefits have accrued to American intercoastal trade and to that of North Atlantic countries with the west coast of South America. From a military standpoint the canal is of utmost importance to the United States since it allows a rapid transfer of the fleet to that ocean where the greatest threat lies. It may be pointed out how fortunate for ocean navigation it is that the land barriers were so narrow at two points on the earth, Suez and Panamá, that canals could be cut through, thereby permitting a

continuous water route in easily navigable latitudes.

898. *The North Pacific trade routes* connect chiefly western North America with eastern Asia. Two principal routes are recognized: (*a*) a shorter northern great-circle route which swings northward almost to the Aleutian Islands and (*b*) a longer southern route which connects the two continents by way of the Hawaiian Islands. This group of islands, the "crossroads of the Pacific," is a converging point for a number of routes including those between Australia and Pacific North America, and Panamá Canal and Asia. The amount of trade moving along the Pacific routes is far less than that in the Atlantic, for the former routes connect a region of small population with one in which, although the population is large, the demands for foreign goods are small.

Ocean Carriers

899. An additional reason, other than that the right of way is furnished by nature, why ocean transportation is cheaper than land transport is that the capital invested in the ocean freighter per ton of freight carried is less than in any form of land carrier. Other costs such as insurance, labor, terminal charges, and power unit of freight volume and weight are also less.

900. Ship Service: Liner and Tramp. Ocean carriers are of two kinds, line ships and tramp ships. Liners ply back and forth across oceans on a regular time schedule and between specified ports. Generally they carry both passengers and freight, but the latter is usually of small bulk and composed of numerous packages which have a high unit value and can stand a high freight rate. Some liners, particularly the larger and finer ones, specialize in passenger traffic. These ships emphasize speed and promptness of arrival. They sail on schedule no matter what load is available. Other liners put greater emphasis on freight and the passenger service is auxiliary.

Most of the world's freight, however, is carried, not on sleek line ships, but on slower, blockier little "tramps," which go where cargo is available and are unrestricted by time schedules. Their movements are uncertain, and as they leave the home port they may not return for a year or several years. They go to the far corners of the earth, picking up and discharging cargo as they can find it. Less beautiful, slower, and many times ungraceful, the tramp steamer does the heavy and dirty work in ocean transport, yet its earnings are often more substantial than the liner's.

901. *Merchant Fleets of the World.* As of about 1939, which fairly well represents the prewar period, Britain possessed about 30 per cent of the total merchant-fleet tonnage. United States was a poor second with 14 per cent, followed in order by Japan, Norway, Germany, Italy, France, and the Netherlands. Compared with the United State's position in foreign trade, in which she ranked close to Great Britain, her merchant fleet engaged in foreign trade was comparatively small. This meant that a considerable part of the country's overseas trade was carried in foreign ships. From the period of the Civil War down to the outbreak of the First World War in 1914, in spite of a marked rise in American foreign trade, there was a fairly steady decline in the merchant fleet. It rose to an unprecedented height during the First World War, only to decline sharply again following that war. The relatively higher operating costs of American ships, compared with those of foreign countries, as a consequence of higher wages and better working conditions for the crews, and higher costs of ship construction place the American merchant fleet at a competitive disadvantage.

The Second World War had the effect of greatly changing the relative positions of the nations as regards size of merchant fleets. In 1946 the United States fleet with 35 million gross tons accounted for just about half the total world tonnage (Fig. 448). Britain's fleet was about what it was in the prewar period or 50 per cent the size of the American fleet. Norway, although her war losses were heavy, ranked third. Germany, Italy, and Japan quite naturally have dropped to inferior positions.

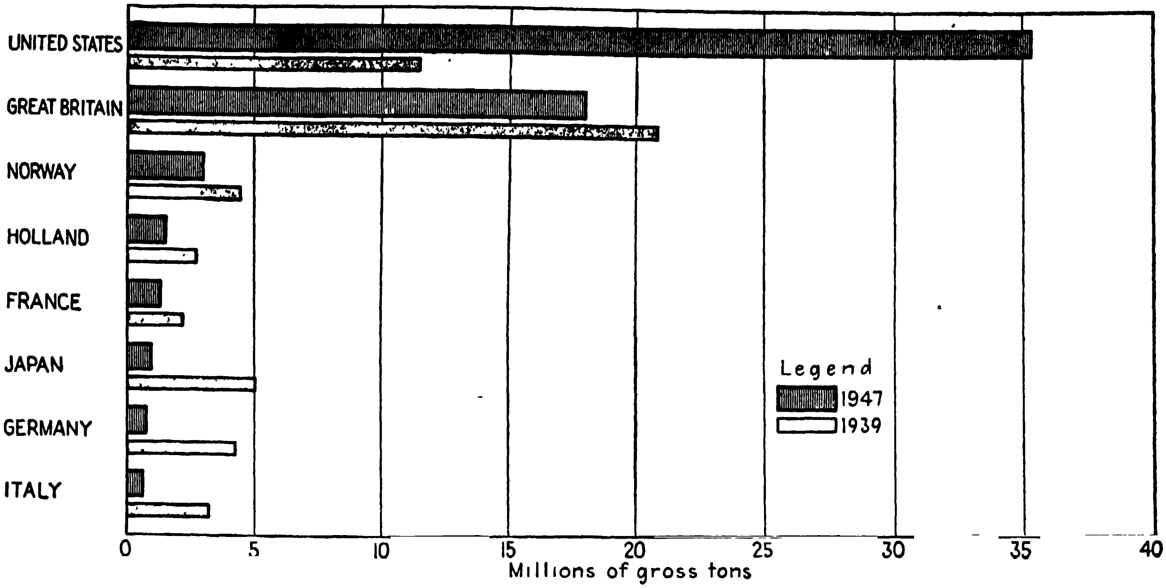


Fig. 448. A comparison of the merchant fleets of the leading maritime countr

AIR TRANSPORTATION

9U:. Possibilities and Limitations. Air transport is a development of the past few decades and is still so recent that it has some aspects of the novel about it. The particular asset of air transport is its speed; the handicap, its inability to carry heavy loads. Thus, at the present time, air transport is chiefly employed in carrying passengers and mail. Only a modest amount of miscellaneous light package express freight is carried. In 1946 United States domestic air lines obtained 89 per cent of their gross revenues from passenger traffic, 7 per cent from mail service, and only 4 per cent from express and freight. Nevertheless, American airline companies for the first time in 1946 began to pay serious attention to improving air-freight service. Rates were reduced, simplified rate structures were put into effect, and specially equipped all-cargo planes were put into operation.

As in the case of ocean routes, air routes are not rigidly confined and restr. ·ed. Yet for the sake of safety and ease of navigation air routes do follow rather closely certain ground marks such as rivers or cities and, at night, lighted beacons. Unlike early rail, motor, and water transport, air transport specializes not in local, but in long-distance carrying. This means that even in those parts of the world where air transport is best developed, such as western Europe and the United States, many trade centers are not served by an air route. There is no such thing as a local air service. On the other hand, air service connects some of the most out-of-the-way places of the earth, preceding rail and motor services into such regions as interior tropical South America and Africa and subarctic Canada.

Almost immediately following the Second World War international and overseas commercial air service was reestablished, and by late 1946 the world's international routes exceeded 300,000 miles, more than twice the prewar mileage. Ten companies, representing eight nations, operated on the North Atlantic route and round-trip schedules rose to more than eight daily in 1946 (Figs. 449*A* and 449*B*). Most of the international commercial flying is in the hands of American, British, French, and Dutch companies. United States domestic air service is the most extensive in the world. Over 700 planes were engaged in this service in 1947. Between some of the larger eastern cities there are as many as 50 round trips daily.

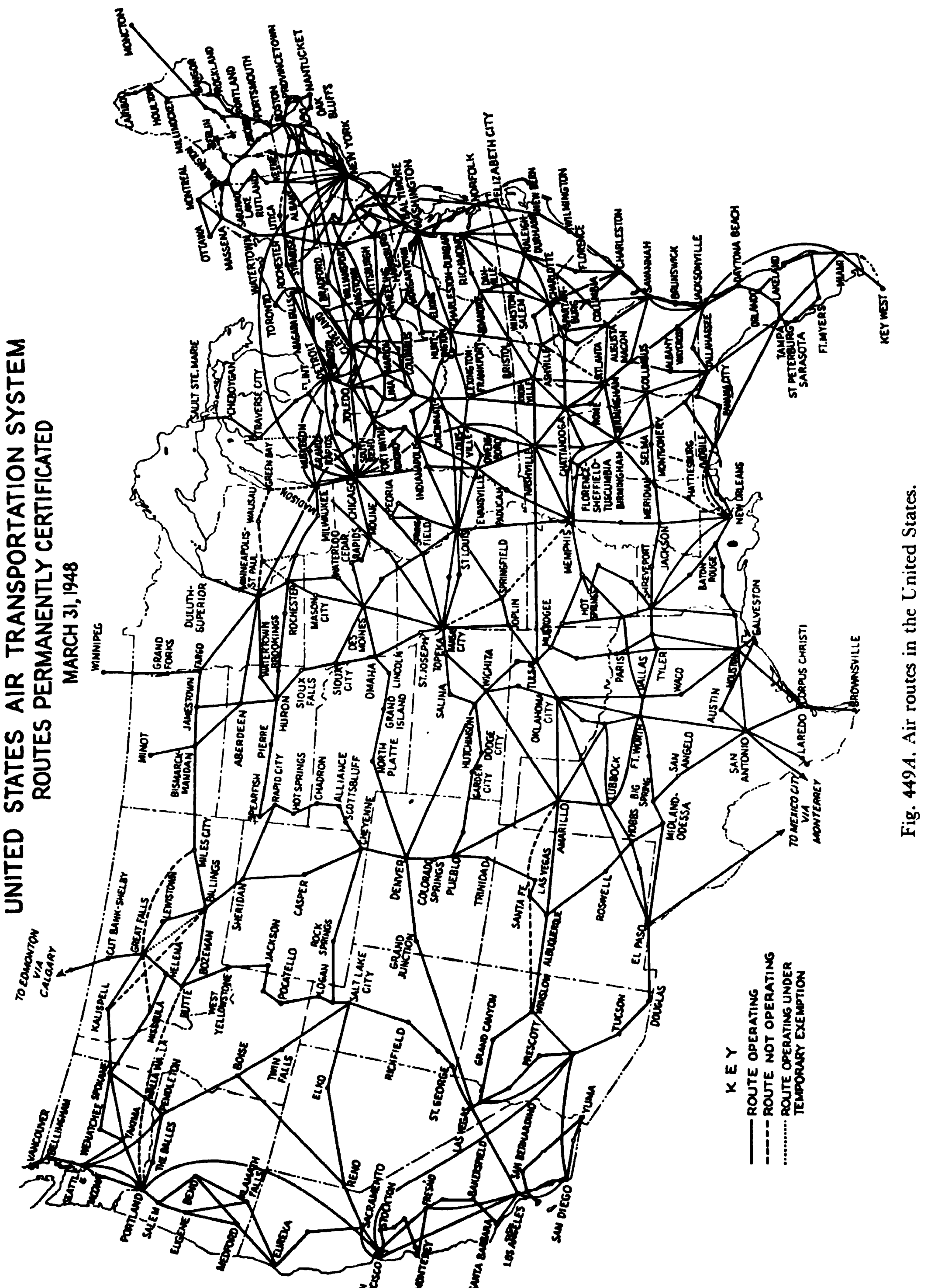


Fig. 449A. Air routes in the United States.

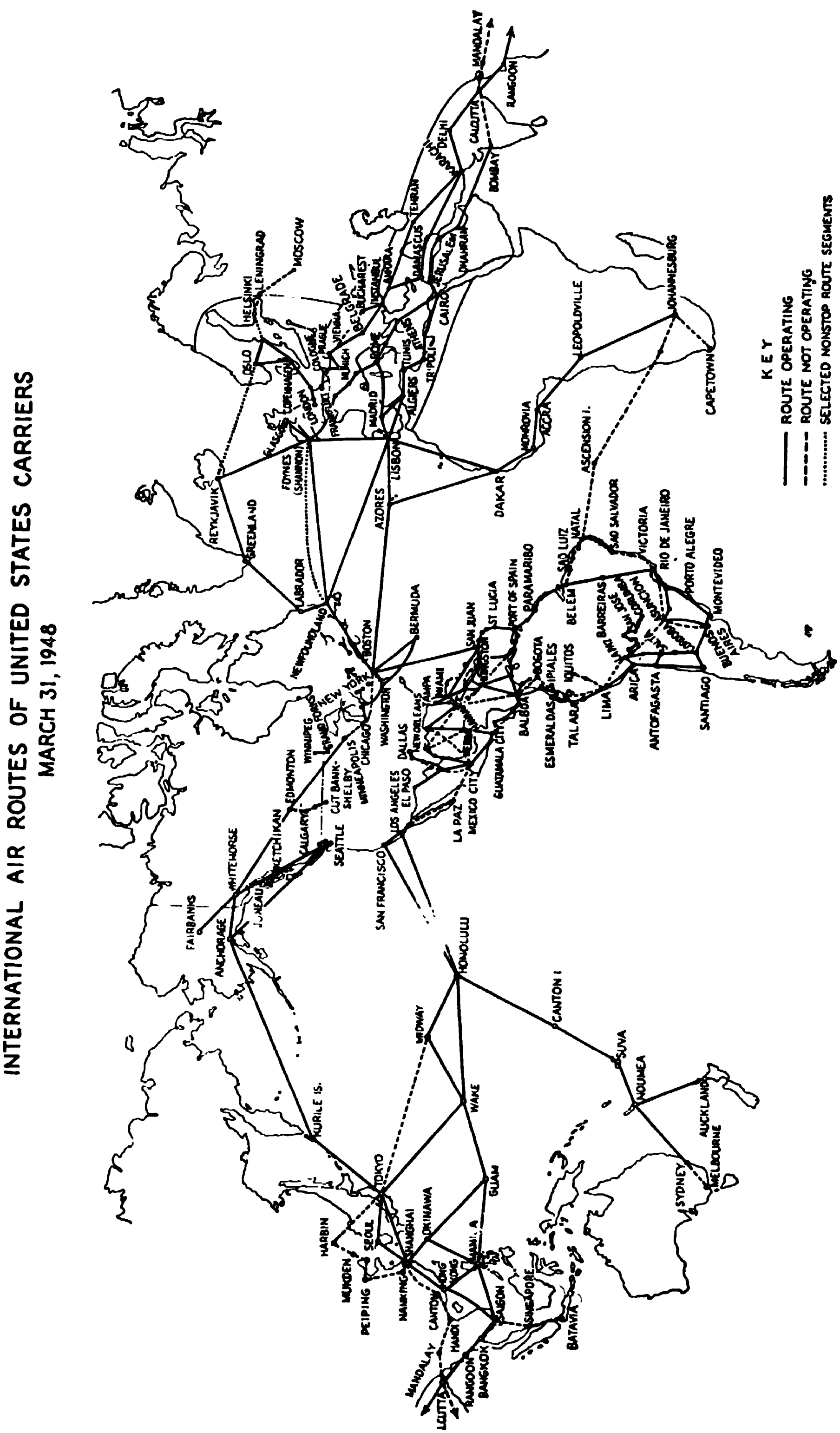


Fig. 449*B*. International air routes of United States lines.

VOICE COMMUNICATIONS—TELEPHONE, TELEGRAPH, CABLE, RADIO

903. Although they are for the purpose of transmitting man's voice and therefore his ideas rather than for transporting man himself or his goods, voice communications are nevertheless vital to trade as we know it in the modern world. One German geographer has used the number of telephones in a city as an index of the city's importance as a trade center. The outstanding merit of telephone, telegraph, cable, and radio is the ultraspeed that they make possible. Since all of them depend upon electricity for transmission, their speed is that of electricity, which is practically instantaneous.

The United States and Canada, or Anglo-America, are the regions where telephones are most used. About 57 per cent of the world's telephones are in the United States; over one-third are in Europe. The average per capita number of telephones in the United States is seven times that of Europe. This striking contrast is due to a number of causes. In part, no doubt, it reflects the Americans' craving to rush things along and save time. In part it is caused by the more numerous and conveniently located public telephone booths in Europe. While in most of the great European cities the per capita number of telephones is below those of American cities, it is the dearth of them in smaller centers and rural districts that draws down the national averages.

Mileage of *telegraph* wire is likewise chiefly concentrated in the United States and Europe, nearly one-third of the world total being in the first-named region. In part this simply reflects an attempt to overcome the handicap of size, for there are a number of countries that have a greater mileage per 1,000 square miles of area, although only one, Canada, with a greater mileage per 100 population. Telegraph and telephone routes in general follow railroads and highways.

The first trans-Atlantic *cable* was laid in 1866, and even yet there is a preponderance of the world's cables in the North Atlantic connecting North America and Europe. They are scarce in the North Pacific, and the other oceans have them chiefly between coastal trade centers. Britain controls around 50 per cent of the world's cables and is the only country whose cables make the complete circuit of the earth.

Radio or wireless, the most recent of the word-transmitting facilities, has had more effect in giving more people an increased familiarity with the world about them than any other form of communication. It has become one of the greatest mediums for advertising as well as a source of news, entertainment, and education. Although radio has been in common use less than three decades, it has already become an intimate part of the lives of North Americans and Europeans. Over 50 per cent of the world's receiving sets are in the United States, no other country even closely approaching our number. Americans should be the best informed people of the world.

Terminals

904. Nature of Terminals. If people or commodities are to be transported by carriers over routes it becomes clear that the produce must be concentrated at certain focal points. If this concentration did not take place, a separate branch line of the route would have to connect each producer with his market. Such a system of transportation is unthinkable. As it is, trunk lines of transportation usually connect important terminal cities where goods and people are collected and distributed. Branch lines have terminals of lesser importance. In such terminal centers facilities for loading, unloading, and storage are provided. As pointed out in an earlier chapter (29) these terminal functions are the most common reason for the origin and growth of cities.

905. Water-route Terminals—Ports. Ports do not grow and prosper merely because they are on the coast, but because they are important gateways of trade. This ability to attract trade reflects certain physical and economic advantages. Among them are (*a*) a good natural harbor, (*b*) a large productive and consuming hinterland, (*c*) easy access to the hinterland, (*d*) location on or close to one or more of the main world trade routes, and (*e*) mechanical facilities

for handling freight and passengers. An ideal harbor is a coastal indentation safe for navigation where a ship is protected against storm waves. The term harbor has nothing to do with trade; it is simply a place of refuge. The ideal harbor is bottle shaped with an entrance wide and deep enough to accommodate traffic but narrow enough so that storm waves cannot enter (Fig. 450). The harbors of New York, San Francisco, and Rio de Janeiro are of this type. A good harbor likewise requires ample depth of water, spaciousness, an extensive water front for pier space, freedom from ice, and small tidal range.

There are hundreds of good harbors that have no trade, and this is due either to the lack of a producing or consuming hinterland, or the absence of easy access to it. The number of high-grade harbors along such indented coasts as those of western Canada and Alaska, southern Chile, or Norway illustrates the point in question. In all these regions the hinterlands are relatively unproductive and meagerly populated so that there is little surplus to export, and import requirements are meager. As a general rule a producing hinterland is also an important consumer but not always so. For example, the western Gulf ports of the United States, such as Houston and Galveston, whose hinterlands have large surpluses of cotton, grain, and oil, are primarily export ports, Houston's exports being roughly twelve times its imports. Portland, Ore., has a similar unbalanced trade. Such a port is somewhat more handicapped than the one whose hinterland is of a kind that results in a better balance between outgoing and incoming cargo, for ships desire to carry full loads in both directions.

The effect of relative ease of access to a hinterland is well illustrated in the case of our Atlantic Seaboard ports. By way of the water-level route of the Hudson and Mohawk valleys New York has an easier natural route to the Middle West than Boston, Philadelphia, or Baltimore. By means of the Erie Canal, which followed the Mohawk Valley, New York was early provided with a water route to its hinterland which did much to establish the pre-

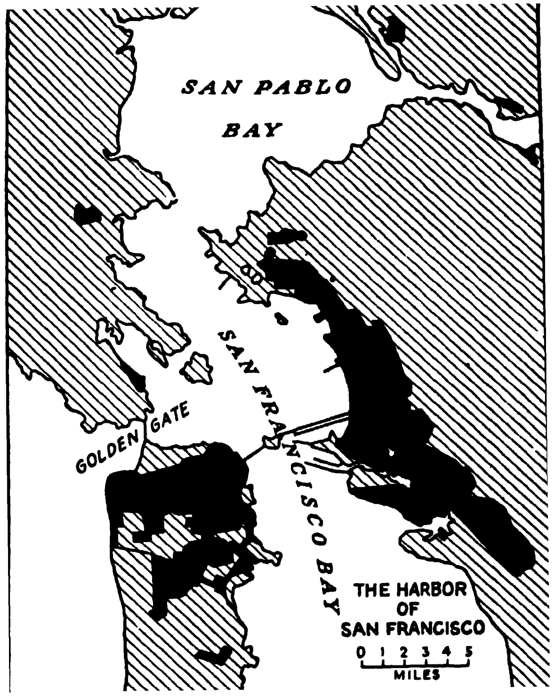


Fig. 450. San Francisco Bay provides one of the world's finest natural harbors.

eminence of that port. The gap formed by the Columbia River through the Cascades provides Portland with easier access to the interior than its rival Seattle has.

A port located on a main route of trade has a far greater chance for growth than one not so ocated. Ships are not attracted to isolated ports well removed from the main lines of traffic, whereas, on the other hand, trade centers with fewer advantages may become important ports of call when they are so located that numerous ships pass their doors. Good illustrations of the importance of location are furnished by such ports as Churchill on Hudson Bay or Alexandrovsk at the base of the Kola Peninsula on the Arctic Ocean. In neither case have the hopes for their development been realized, and in part this is due to their far removal from any important shipping lanes.

Mechanical facilities in form of wharves, warehouses, cranes, tracks, etc., are features of a port that can be provided by the trade center itself (Figs. 451 and 452). The last few dec-

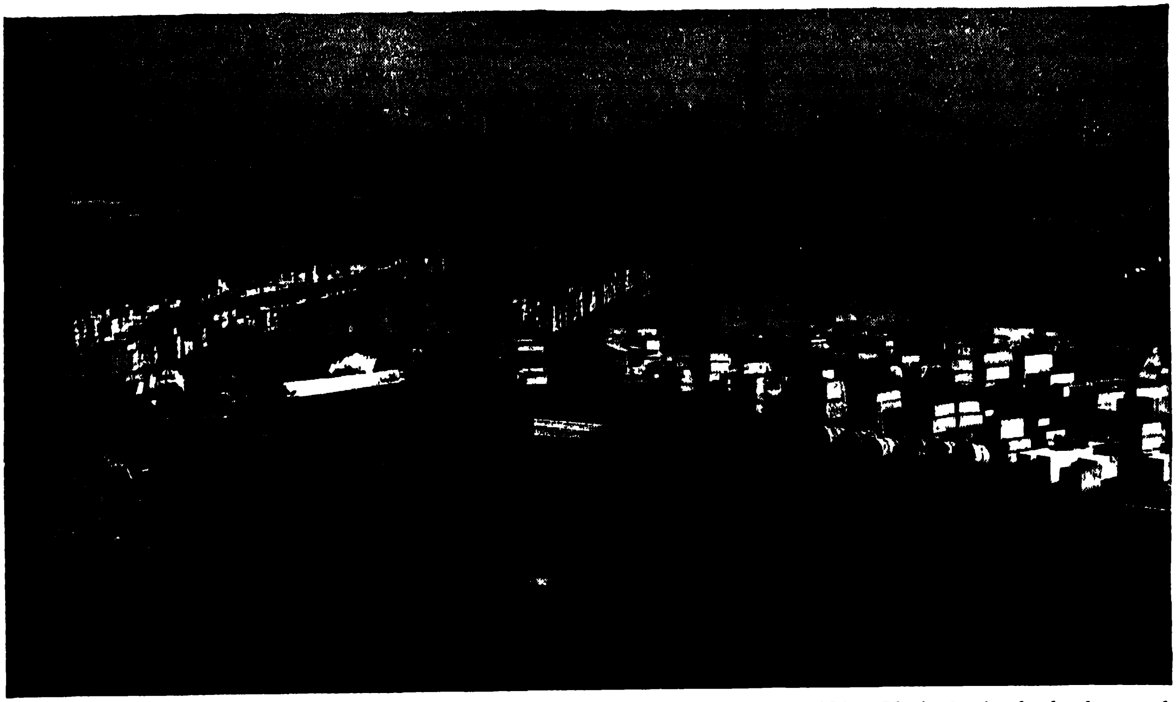


Fig. 451. The Hudson River piers from the New Jersey side of the river. Skyline of New York city in the background. (*Port of New York Authority.*)

Fig. 452. The port of Mobile, Ala. (*Alabama State Department of Docks and Terminals.*)

ades have seen marked competition on the part of ports for providing modern and efficient equipment for handling cargo and the quick dispatch of ships. Realizing the part that mechanical facilities play in attracting commerce, trade centers have given this feature much publicity in their advertising.

906. Types of Ocean Ports and Their Services. Most ports lie at the ends of transoceanic trade routes, and they function therefore as *terminal ports*. Ships enter them to discharge cargoes that are definitely assigned to that particular port and the hinterland that it serves. New York, for example, is primarily a terminal port. There are other ports, however, whose function is more largely that of a middleman between other ports. These are called *entrepôt ports*, or, as the name suggests, "between ports"—ports for other ports. At the entrepôt, warehousing and processing may occur before reshipment. Singapore is an important entrepôt port in southeastern Asia, acting as the middleman for the world's most important source of tropical raw materials. Hongkong serves in a similar capacity. Before the last war London received cargoes from the far corners of the earth, and from there these cargoes were distributed in smaller amounts to other ports in northwestern Europe and beyond. Somewhat different is the function of the *free port*, which permits ships to unload their cargoes within a fenced-off "free zone," where they are sorted, perhaps processed, or warehoused without payment of duty. Here the goods may be sold and reloaded on other ships. Payment of duty occurs only when the goods pass from the "free zone" into the city. The advantage of this free-port function is that the middleman transaction involves no customs charge and that fee is paid only once, *viz.*, when the goods enter the country of their final destination.

Retrospect and Conclusion

907. Geographic Elements and Their Natural Groupings. The content of this book has been primarily concerned with the elements of geography; those groups of features, natural and cultural, which together make up the face of the earth. The treatment has been of the several groups of geographic elements singly and individually, although pains have been taken to point out the interrelations between them. This description and analysis of the geographic elements individually was considered to be necessary, for only as the separate elements are recognized and understood and their world distributions described and explained is there laid a substantial foundation for understanding the earth's surface in whole or in part. It is impossible, for example, to understand a plant as a functioning organism without first comprehending the structure and function of its individual parts—roots, stem, and leaves. No more is it possible to understand the geographic character of the earth's surface or any part of it without first being acquainted with the individual elements of its geography. But just as the botanist is ultimately concerned with the *whole* plant, so the geographer is concerned with the complex patterns of the whole earth and its separate regions, made up as they are of the interrelated and interdependent geographic elements.

908. All Natural Features of a Region Are Interrelated. It needs to be emphasized that the individual elements neither of a plant nor of a region exist separately and for and by themselves as self-sufficient units. Leaves, roots, and stems can have no separate existence apart from each other; they are only interrelated and interdependent parts of a larger whole. Climate, landforms, drainage, natural vegetation, and soils likewise never exist separately and apart from each other in nature. For any portion of the earth they exist together not only in an areal sense but likewise as interrelated elements of a region, the parts of which are geared together so that they are interdependent, each element reacting upon all the others and in turn being reacted upon by them. The soil of a region, for example, can scarcely be thought of as having a separate existence apart from the bedrock, landforms, climate, vegetation, and drainage, all of which have influenced its evolution and character. The bonds of interrelationship between the several natural elements or features of a region are extremely complicated. The total assemblage of interrelated natural features, within a region is called its *natural landscape*.

909. Climatically Induced Natural Landscapes. In an earlier chapter it has been pointed out that the complex of *natural* features which characterizes any part, or the whole, of the earth's surface is the result of two sets of forces and their associated processes acting upon the solid, liquid, and gaseous earth materials. One of these two sources of energy is the forces residing within the earth; the other is provided by the sun.

It was further noted that the interior, or tectonic, forces and processes (gravitational, volcanic, and diastrophic) are the cause, for instance, of variations in earth materials and likewise in many of the larger aspects of surface configuration from one part of the earth to another. The nature of these forces resident within the earth's interior are not so well known, and the distribution of types of surface features

(mountains, plateaus, plains) resulting from them does not seem to follow any repeated world-distribution pattern, as do climatic and soil types, for instance. Plains, plateaus, or mountains may occur at the pole as well as at the equator and along the eastern or the western sides of continents. Mineral deposits, likewise, seem to follow no apparent repeated world-distribution patterns.

Solar energy, the second of the two great forces fashioning the earth's surface, expresses itself most directly through climatic processes and indirectly through a great variety of physical and chemical reactions, two of the most important being the weathering of rocks and the growth, death, and decay of plants. The gradational agents (streams, waves, wind, glaciers) likewise are principally of climatic and gravitational origin. Here, then, in a vast laboratory, composed of the thin outer shell of the solid earth and the adjacent lower layers of atmosphere with which it is in contact, is the focus of an unbelievably complicated set of reactions, where sun-induced processes are acting upon earth materials and major surface forms of tectonic origin to produce the present array of natural features with which the earth's surface is adorned.

910. *Mature Natural Landscape.* The very name (weathering) of the processes by which solid rock is broken down into the mantle rock or regolith cover emphasizes the role of such atmospheric conditions or elements as temperature, moisture, oxygen, and carbon dioxide in rock destruction. Temperature and moisture conditions are likewise primary in determining the nature of the vegetation cover, while climate and climatically induced vegetation play significant roles in soil formation and quality. Many of the drainage, and some of the landform, features as well are the result of weathering and gradational agents, stemming indirectly from climatic energy. The regolith cover, composed of both inorganic and organic materials, and the vegetation cover develop in a region together; both responding to the conditions imposed by climate, and each in turn modifying the character of the other. It becomes evident, therefore, that within any particular region the climatic forces peculiar to it, if undisturbed over a long period of time, will produce a layer of mantle rock the depth and quality of which represent a state of balance between the rate of weathering and the rate of removal. This regolith is, in turn, covered by a mantle of vegetation, nourished by the soil layer underneath but likewise in harmony with the temperature and rainfall conditions surrounding it. Through the character and intensity of gradational forces, minor landform features and drainage conditions, in a somewhat lesser degree, likewise are brought into step with the atmospheric environment, so that the whole landscape complex bears the stamp of the regional climate. Landforms, which are so much influenced by tectonic forces, character of earth materials, and stage of development, usually bear this stamp of climatic environment much less conspicuously than do vegetation and soils, for instance. Within a large region of relatively uniform climate, there is a tendency, nevertheless, for many of its natural features, each adjusted to and in balance with all the others, to develop a considerable degree of similarity throughout. When that state of balance has been reached, the region may be said to have a *mature* natural landscape. The reason that completely mature landscapes are rare is due in a measure to the constant operation of the tectonic forces, resulting in elevation or depression of the land. A change in climate similarly disrupts progress toward maturity. In northwestern Europe and northern North America, for instance, continental glaciation, resulting from climatic change, left a landscape which, in many respects, is lacking in perfected development. Variety in earth materials adds further disharmony. Man, too, through removing the natural vegetation cover, cultivating the soil damming the rivers, and numerous other activities tends to disrupt the balance sought by nature.

911. Climate and the World Pattern: Geographic Realms. It has been emphasized in an earlier section of this book that (*a*) climates tend to remain relatively uniform over extensive areas, and (*b*) similar climates are repeated on

the land masses in characteristic latitudinal and continental locations. There is a definite and repeated world pattern in the distribution of climatic elements which permits of classifying climates into a relatively few large types. It now becomes apparent that these extensive, and often far separated, regions included within the same type of climate are likely to possess similarities in certain other natural features as well. A student cannot have progressed thus far in his study of the physical elements of geography without becoming aware of broad but clearly defined similarities in the world-distribution patterns of climatic, vegetation, and soil types (Fig. 312). To these great world subdivisions, bearing as they do the stamp of a broadly similar climatic environment upon their vegetation and soil and, in a lesser degree, upon gradational landform and drainage features as well, the name *geographic realms* may be applied. For reasons noted in the previous article, too great a degree of similarity within a realm is not to be expected.

Since the character of the bedrock, size and quality of mineral deposits, and the nature of tectonic landforms are chiefly the result of interior forces, these features usually do not fit harmoniously into a scheme of world subdivisions based primarily upon climatic imprint.

912. Man's Place in the Geographic Realm. At this point the question logically arises as to whether the world patterns of population and the culture features created by human beings have any important coincidence with the pattern of the physical realms. Can it be that the inanimate earth so influences human destinies that peoples are relatively similar in their accomplishments and modes of work within similar physical environments? Within a great physical realm, possessing as it does broad similarities in natural endowments, it would not be unusual if there were a degree of similarity in some of its land-use features as well. Actually this is the case. On the other hand, man's activities within an area are influenced by so many forces, social, political, and economic, many times not directly related to the natural earth, that it is unreasonable to expect similar environments to produce similar types of land use. The influence of environment is passive, not active. It provides the natural endowments, to be sure, but it never determines how and to what degree those endowments shall be used. Physical earth sets limitations and hindrances, but it is man himself who determines the course of action. It is not to be expected that human groups with different physical and mental characteristics, with contrasting historical and social backgrounds, and in different stages of economic development, will solve their environmental problems in a similar manner. Strong coincidence between physical and cultural patterns is scarcely to be expected, therefore. Moreover man's behavior is not consistently rational and predictable, so that serious errors arise when an attempt is made to explain culture as a conscious adjustment to environment. Inherited traditions and deeply rooted habits of thought are often of greater importance in determining human behavior than is the passive environment. This is not to belittle the significance of physical earth in human affairs— to deny its importance is as erroneous as to overemphasize and oversimplify its influence. But similar natural environments can be very significant in the life and work of two groups of peoples and those peoples still not be using the physical endowments in the same way. *In other words the environment's importance is not measured by the degree of culture uniformity prevailing within a broad realm of similar natural equipment.*

913. Culture Patterns Often Not Coincident with Physical Realms. As a general rule, peoples with a primitive culture or those engrossed in a simple subsistence agricultural economy appear to find fewer different ways in which to use the similar physical endowments of a realm than do complex industrial-commercial civilizations. In the low-latitude and the high-latitude realms, therefore, where civilization in general is on a lower plane of material development, there appears to be a modest amount of intrarealm culture similarity. Regional differences are still conspicuous, however. In the middle-latitude realms, which include the great modern centers of western civilization on either side of the North Atlantic Ocean, as well as the

center of Oriental culture in eastern Asia, the fitting of culture into the pattern of the physical realms is not satisfactory. One has a feeling that such an organization is largely forced and unreal.

914. *Realms of Small Cultural Development.* It has been pointed out earlier that environment acts chiefly in a limiting sense; its effects are negative rather than positive. It may render a particular form of land use difficult or even prohibit it. This passive effect of the physical environment is clearly apparent in the distribution of man and his works over the face of the earth. Largely because of the poverty of physical potentialities, but in some instances as the result of serious positive handicaps, over the greater share of the earth's surface man has made slight permanent impression, or even none at all in parts. These lands of little or no development include the *ice caps, tundra, dry lands* (semiarid *steppes* as well as *deserts*), *taiga* or subarctic forest lands, and large parts of the *tropical forests* and the *tropical savannas.* Of these only the ice caps are entirely without permanent settlements. The driest parts of some deserts are likewise without human life. Within some of these realms there are enough noteworthy exceptions to the general rule of sparse population and scant economic development to prevent one from falling into the errors of environmental determinism. Witness, for example, the cases of overcrowded and intensively cultivated Java and India within the wet tropics.

915. *Realms of Important Cultural Development.* It is chiefly in the humid and subhumid realms of the middle latitudes that man has most completely modified the physical earth and adapted its natural resources to his needs. In these regions much of the original native vegetation, either forest or grass, has been removed and the land put into cultivated crops. Regional specialization in production has promoted the development of communication nets of various degrees of complexity. The commerce fostered by this specialization has been instrumental in causing the development and growth of numerous towns and cities. Within these physical realms of important economic development in the middle latitudes there are fewer common cultural characteristics than is true of the less well developed realms. This appears to stem from the fact that men in more advanced stages of development are more versatile in their ways of utilizing physical environment than are primitive and backward peoples. Wider variations in kinds and intensities of land use within similar physical areas are the result. Within the well-developed parts of the middle latitudes the cultural heritage of the occupying group is usually of greater importance than the physical environment in influencing the culture patterns. For example, within the middle-latitude mixed forest lands (including marine west coast, humid subtropical, and humid continental regions), where more than half the earth's population resides, the land-utilization contrasts of the first order of importance are between the regions of Occidental culture in Europe and North America on the one hand, and those of Oriental culture in eastern and southeastern Asia on the other. Within the broad regions over which these two cultures are spread there exist markedly contrasting environments, but these do not result in such fundamental contrasts in land use and utilization of resources as do the dissimilar cultures.

916. A World System of Geographic Regions Impracticable. Considering the number of elements that enter into the geography of any region, it is highly improbable that a particular combination of *all* of them would be found repeated in widely separated parts of the earth. There are, to be sure, far separated regions that resemble each other in one, and sometimes even two or three, geographic-element complexes. For example, the Spring Wheat Region of the United States and Canada resembles the Spring Wheat Region of Soviet Russia in certain physical characteristics and likewise in its agricultural-element complex. But obviously if they were exactly alike in their agricultural elements, they would still be far from geographically alike. The notion of a world system or classification of geographic regions together with a schematic explanation of the same is clearly unsound. It seems to be based upon the erroneous concept that an area is an organic

whole, an actual object. In reality an area is only the sum total of more or less related elements. It is quite possible, on the other hand, to treat the geography of the world regionally *outside* any scheme of world classification, but such a description of individual geographic regions clearly lies outside the scope of the present book.

In terms of a scheme of world classification of the geographic elements the authors of "The Elements of Geography" have employed the regional concept as far as they felt it was warranted. Beginning with a world classification of the most primary physical element, climate, it was later developed that certain other natural elements, particularly native vegetation and soils, show striking similarities in their world distribution to that of climate. From this evolves the concept of a world classification of physical or natural realms (Fig. 312). But since a number of the physical elements have a world distribution quite at variance with that of the climatic pattern, the notion even of physical realms should not be pushed too far. It is a useful concept as far as it goes, but it has genuine limitations. The Amazon Valley and the Congo Basin no doubt bear resemblance in their climates, and in their plant covers and soils as well, but the two regions are far from being specimens of the same physical, let alone geographic, species. If then it appears dubiously possible to set up a scheme of world classification involving the physical geographic elements only, how much more difficult the task becomes when man and his works are included. It is the authors' belief that it is impossible to arrange the regions of the earth to form a single system that will describe the world even in outline. With this conviction in mind they have refrained from attempting to synthesize the geographic elements into any semblance of a world system.

Appendices

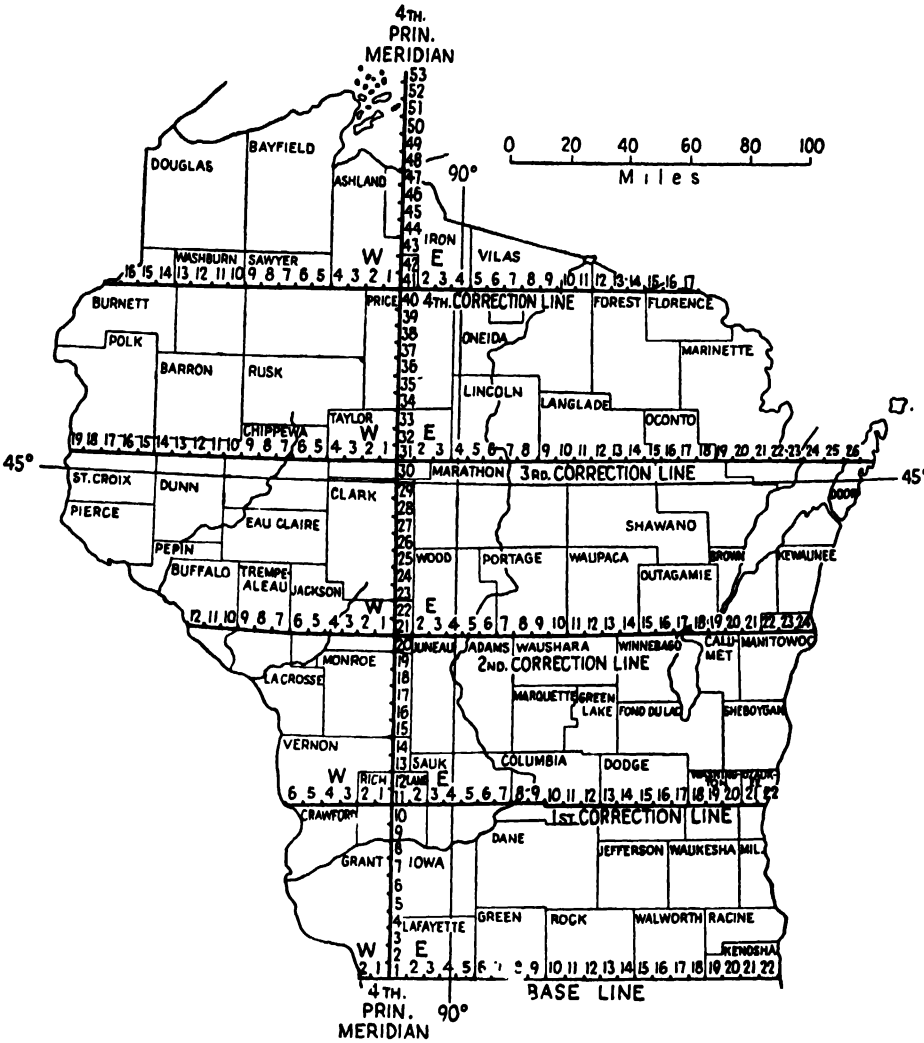


Fig. B. The principal meridian (4th) of Wisconsin and its base line, which is the southern boundary of the state. This map shows correction lines and town and range numbers.

land are described by a system known as "metes and bounds." In that system an arbitrary point is taken, such for example as a projecting rock, a tree, or some significant point on the bank of a river or lake. The property is then bounded by lines run in a given compass direction for a certain distance, then in another direction for a specified distance, and so on around to the point of beginning. This system has often led to conflict over property lines because after a time the tree, stone or other arbitrary beginning point has been lost or its location has changed. Moreover, the stated distances were sometimes measured inexactly, as in parts of Texas, for example, where some of the early Spanish land grants are said to have been measured in terms of the length of a lariat rope or of how far a horse could walk in a given time. Such lines often did not surround rectangular parcels of land, and seldom did the plots of land have any consistent pattern of shape with respect to the cardinal compass directions.

This lack of coordination is plainly apparent in the road patterns to be seen in detailed maps of New England, Texas, and other states. In some North American localities the present small parcels of land are subdivisions of grants made by the kings of England, France, or Spain to noblemen or to the sponsors of settlement projects. In French Canada or French Louisiana, for example, the present farms

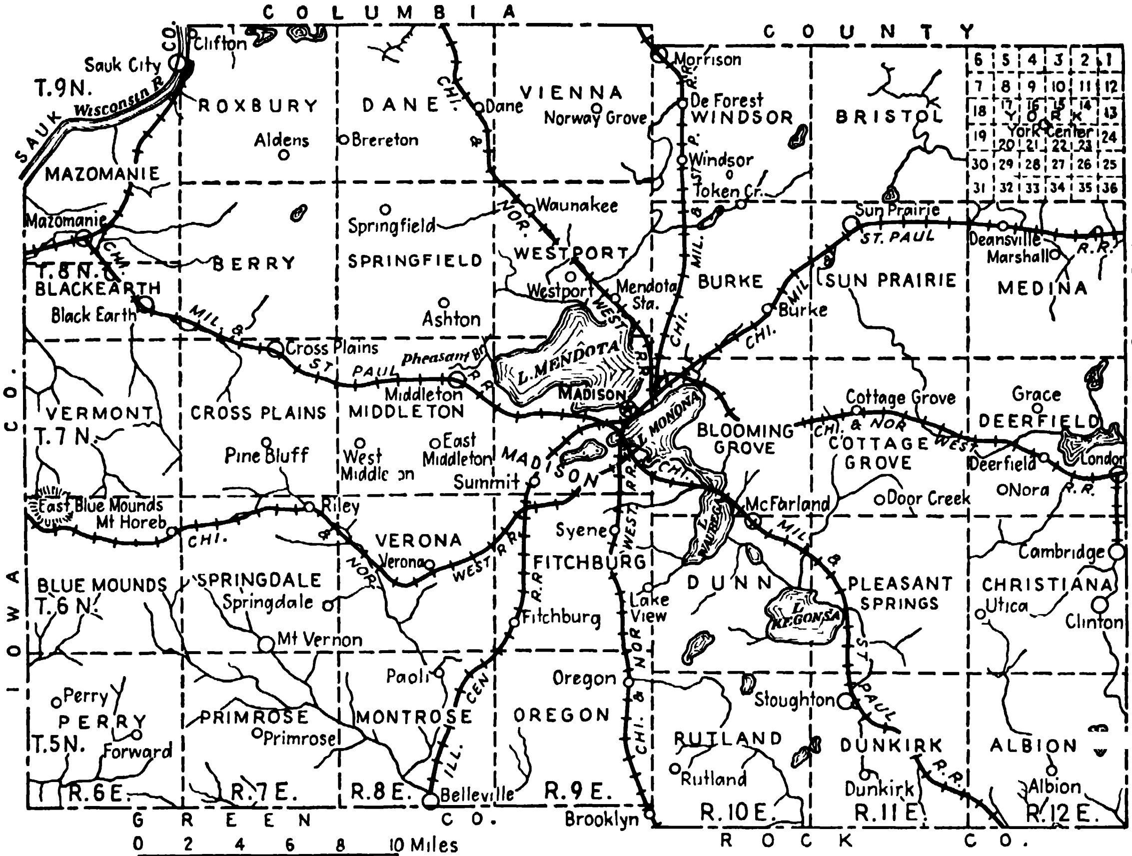
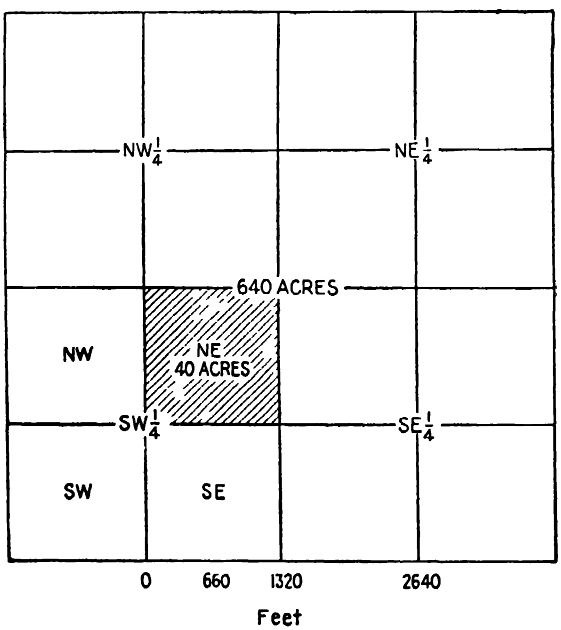


Fig. *C*. The standard system of numbering used for the sections within the township. The sections of all the other townships in Dane County are numbered in the same manner, beginning with the northeastern corner.



often are rectangular but are very long and narrow, their narrow frontage being upon a river and their length extending at right angles from the river, regardless of compass direction. Some of the counties of the Province of Quebec may be seen to have the same shape. They were established at a time when river frontage was a most prized possession but the land of the interior had little value. Various systems more or less like that of metes and bounds are prevalent in most of Europe and, in fact, in the larger part of the world.

Fig. *D*. The description and location of parts of sections, under the rectangular survey, is by quarter sections, and, within these, by 40-acre tracts, designated by the compass position of each within its quarter section.

APPENDIX D

A SELECTED LIST OF UNITED STATES TOPOGRAPHIC QUADRANGLES

The topographic quadrangles indicated below have been selected from those published by the United States Geological Survey because they illustrate in map form certain of the landforms discussed in the text. Some of the subjects discussed, ice-scoured plains, for example, do not find clear illustration in any of the United States Topographic Quadrangles now published and are therefore omitted from the list.

Certain of the maps named below may be used to illustrate more than one class of features, and their names are repeated. Such maps are indicated by the asterisk. In some instances two or three adjacent quadrangles are required to show adequately the extent of the feature in question. Such are indicated as a series by being listed in series.

These topographic quadrangles may be obtained from the United States Geological Survey, Washington, D.C. In the following list, sheets of sizes other than standard are marked "(*special*)."

Plains of Stream Degradation

Newly emerged plains:
- Bladen and Everett City, Ga.
- Cambon, Fla.
- Chicora, S.C.
- Moniac, Ga.-Fla.

Higher and better drained coastal plain:
- Allendale and Olar, S.C.
- Bamberg, S.C.
- Forest, Miss.
- Springhope and Rocky Mount, N.C.

Plains with cuestaform ridges and escarpments:
- Blanchardville and Blue Mounds, Wis.
- Epes, Ala.
- Fond du Lac and Neenah, Wis.
- Kendall and Mauston, Wis.*
- Llano, Tex.*
- Nashville, Tenn.*
- New Boston and Linden, Tex.
- Niagara Falls, Tonawanda, and Lockport, N.Y.
- Pelahatchie and Morton, Miss.

Knobs and outliers on cuestaform plains:
- Big Clifty, Ky.*
- Franklin, Tenn.
- Kendall and Mauston, Wis.*
- Llano, Tex.*
- Nashville, Tenn.*

Young plains (mainly in glacial drift):
- Gillespie, Ill.*
- La Salle, Ill.*
- Macon, Mo.
- Paulding, Ohio*
- Ray, N.D.*

Rough, maturely dissected plains:
- La Farge, Wis.
- Newcomerstown, Ohio
- Nortonville, Ky.

Dissected river bluffs (river breaks):
- Ray, N.D.*
- Porcupine Valley and Spring Creek, Mont.

Old-age plain:
- Mount Carmel, Ill.-Ind.
- Owensboro, Ind.-Ky.

Peneplains with monadnocks:
- Atlanta and Marietta, Ga.
- Gastonia, N.C.
- Kings Mountain, N.C.

Karst plains:
- Big Clifty, Ky.*
- Interlachen, Fla.
- Mammoth Cave, Ky.
- Princeton, Ky.
- Williston, Fla.

Plains of Stream Aggradation

Delta margin:
- Black Bay and Pt. à la Hache,* La.
- Dulac, La.
- East Delta, La. (out of print)
- Timbalier, La. (out of print)

Narrow levees:
- Bayou du Large, La.
- Empire, La.
- Luling, La.
- Pt. à la Hache, La.*
- Shell Beach, La.

Wide levees:
- Baton Rouge, La.
- New Orleans East and New Orleans West, La.

Wide alluvial floodplains:
- Bayou Sara, La.
- Clarksdale, Miss.
- Marks, Miss.
- Memphis, Tenn.–Ark.
- Vicksburg, Miss.–La.

Narrow floodplains:
- Chester, Ill.–Mo.
- Gays Mills, Wis.
- Ogallala, Neb.*
- Prairie du Chien, Wis.*

Alluvial terraces:
- East Cincinnati, Ohio
- Malaga, Wash.
- Prairie du Chien, Wis.*
- Tarboro, N.C.

Alluvial fans and piedmont alluvial plains:
- Cucamonga and San Bernardino, Calif.
- Levis, Calif.
- Pacoima and Sunland, Calif.
- Whittier, Calif.

Plains of older alluvium:
- Assinniboine, Mont.
- Colorado Springs, Colo.
- Eaton, Colo.
- Sanborn, Colo.
- Vilas, Colo.

Glacial Drift Plains

Till plains (younger drift):
- Poorly drained:
  - Chokio, Minn.
  - Lansing, Mich.
  - Neshkoro, Wis.
- Well drained:
  - La Salle, Ill.*
  - Slater, Iowa
  - Upper Sandusky, Ohio
- With drumlins:
  - Boston* and Boston Bay, Mass.
  - Clyde and Weedsport, N.Y.
  - Palmyra, N.Y.
  - Sun Prairie and Stoughton, Wis.
- With eskers:
  - Fowlerville, Mich.
  - Rives Junction, Mich.*
  - St. Francis, Minn.

Till plains (older drift):
- Albia and Pella, Iowa
- Gillespie, Ill.*

Till plains (relief controlled by bedrock features):
- Baraboo, Wis.
- Old Mystic, Jewett City, and Plainfield, Conn.
- Youngstown, Ohio

Marginal moraines:
- Kettle-moraine regions (large area):
  - Pelican Rapids and Vergas, Minn.
- Kettle-moraine belts (with associated pitted outwash plains):
  - Rives Junction* and Stockbridge, Mich.
  - Schoolcraft, Mich.
  - St. Croix Dalles, Wis.–Minn.
  - Whitewater, Wis.

Lake plains (glacial):
- Detroit, Highland Park, Dearborn, and Royal Oak, Mich.
- Fargo, N.D.–Minn.
- Genoa, Ohio
- Paulding, Ohio*
- Ridgeway, N.Y.

Plains in Dry Climates

Eolian sand plains:
- Browns Creek, Neb.
- North Platte, Neb.
- Ogallala, Neb.*
- Tennis, Kans.

Loess plains (stream eroded):
- Omaha and Vicinity, Neb. and Iowa (special)
- Red Cloud, Neb.
- York, Neb.

Shore Features of Plains

Ria shorelines:
- Bath and Boothbay, Maine
- Boston, Mass.*
- Choptank, Md.
- Kilmarnock, Va.

Deposited shore features:
- Offshore bars:
  - Fire Island, N.Y.
  - Lopena Island and Saltillo Ranch, Tex.
  - Newburyport, Mass.
  - Ocean City and Green Run, Md.
- Spits and hooks:
  - Cape Henlopen, Del.*
  - Erie, Pa.
  - Provincetown, Mass.
  - St. Joseph Point and Cape San Blas, Fla.
- Shore dunes:
  - Cape Henlopen* and Rehoboth, Del.
  - Fennville, Mich.
  - Three Oaks, Mich.

Dry-plateau Features

Plateau valleys and escarpments:
- Bisuka, Idaho
- Bright Angel, Ariz.
- Camp Verde, Ariz.*
- Hanford and Scooteney Lake, Wash.

Mesas and buttes:
- Camp Verde, Ariz.*
- Mesa de Maya, Colo.
- Raton, N.M.
- Ship Rock, N.M.*
- Tascotal Mesa, Tex.

Plateau bolsons:
- Ballarat, Calif.–Nev.*
- Carson Sink, Nev.*
- Cienega Springs, N.M.
- Eugene Mt. Area, Nev.
- Silver Peak, Nev.–Calif.*

Hill Lands

Stream-eroded hills in horizontal strata:
- Arnoldsburg, W.Va.
- Bald Knob, W.Va.
- Clarksburg, W.Va.
- Confluence, Pa.
- Fayetteville, W.Va. (plateau features)
- Parkersburg, W.Va.–Ohio

Badlands:
- Rock Springs, Wyo.

Hills in folded sedimentary strata:
- Craigsville, Va.
- Harrisburg, Pa.
- Hyndman, Pa.
- Mount Union, Pa.
- Paw Paw, Md.–W.Va.–Pa.
- Winding Stair, Okla.

Hills in complex rocks:
- Asheville and Mt. Mitchell, N.C.–Tenn.
- Knoxville, Tenn. N.C.

Hills in areas of linear faulting:
- McKittrick, Calif.
- Pt. Reyes, Calif.
- Priest Valley, Calif.
- San Mateo, Calif.

Glaciated hill lands:
- In crystalline rock:
  - Allagash Falls, Maine
  - Bolton, N.Y.
  - Greenlaw, Maine
- In horizontal strata:
  - Bath and Hammondsport, N.Y.
  - Cortland, N.Y.

Mountains

Volcanic peaks:
- Crater Lake National Park, Ore.
- Lassen Volcanic National Park, Calif.
- Maiden Peak, Ore.
- Mount Hood, Ore.
- Mount Rainier National Park, Wash.*

Laccolithic mountains:
- Abajo, Utah (out of print)
- Fort Benton, Mont. (out of print)
- Henry Mountains, Utah (out of print)

Fault-block mountains:
- Ballarat* and Furnace Creek, Calif.–Nev.
- Carson Sink, Nev.*
- Dome Rock Mts., Ariz.–Calif.
- Sequoia and General Grant National Parks, Calif. (special)*
- Silver Peak, Nev.–Calif.*

Mountain foothills of the hogback-ridge type:
- Boulder, Colo.
- Loveland, Colo.
- Rapid, S.D.
- Ship Rock, N.M.*

Glaciated mountains:
- Glacier National Park (special)
- Hamilton, Mont.
- Hayden Peak, Utah
- Mount Rainier National Park, Wash.*
- Sequoia and General Grant National Parks, Calif. (special)*

Emerged highland shore features:
- La Jolla, Calif.
- Port San Luis, Calif.
- San Pedro Hills, Calif.
- San Ysidro and Pt. Loma, Calif.
- Santa Ana, Calif.
- Solstice Canyon and Las Flores, Calif.

Fiords:
- Coast and Geodetic Survey Chart 8519
- Reconnaissance Map—Alaska Railroad, Seward to Matanuska Coal Field (special)
- Takoma and Snohomish, Wash.
- Valdez and Vicinity, Alaska

APPENDIX E: *Principal Subdivisions of Earth History*

PRINCIPAL SUBDIVISIONS OF EARTH HISTORY AND SOME OF ITS EVENTS AS THEY ARE RECORDED IN THE ROCKS OF NORTH AMERICA

MORE RECENT TIME ⟶ THE ENTIRE SPAN OF EARTH HISTORY IS ESTIMATED TO BE MORE THAN 1,500,000,000 YEARS. PROBABLY TWO THIRDS OF IT HAD ELAPSED BEFORE CAMBRIAN TIME. ⟵ EARLIER TIME

THE SPACES ALLOTTED BELOW TO THE ERAS AND PERIODS ARE NOT IN PROPORTION TO THEIR ESTIMATED DURATION

ERA			PERIOD	TOPOGRAPHIC DEVELOPMENTS	BIOLOGIC DEVELOPMENTS	PREVAILING CLASSES OF ROCKS IN THE GEOLOGIC REGIONS OF NORTH AMERICA
CENOZOIC	ERA OF MODERN LIFE	DUR. EST. AT ± 4% OF ALL GEOL. TIME	QUATERNARY: RECENT (ESTIMATED AT ± 25000 YRS.)	PRESENT TECTONIC AND GRADATIONAL LAND FORMS	THE DEVELOPMENT AND DOMINANCE OF INTELLIGENT MAN	ALLUVIUMS—OLD & NEW—GLACIAL DRIFT, LOESS
			QUATERNARY: PLEISTOCENE	CALIF. COAST MTS. APPEAR. THE GREAT ICE AGE	NEW SPECIES OF PLANTS AND ANIMALS. APPEARANCE OF PRIMITIVE MAN	
			TERTIARY: PLIOCENE, MIOCENE, OLIGOCENE, EOCENE	ELEVATION OF ROCKY, SIERRA NEVADA & CASCADE MTS., THE COLORADO & COLUMBIA PLATEAUS, AND THE GREAT BASIN	DEVELOPMENT OF MAMMALS (PRIMITIVE TYPES OF ELEPHANTS, HORSES, DEER, CATS, DOGS, WHALES & MANY OTHERS, INCLUDING FIRST APES) BIRDS & TREES SIMILAR TO MODERN TYPES	
GENERAL EROSION INTERVAL						
MESOZOIC	ERA OF MEDIEVAL LIFE	DURATION EST. AT ABOUT 8% OF ALL GEOL. TIME	CRETACEOUS (ROCKY MT COAL DEPOSITS)	LAST GREAT SUBMERGENCE, GULF OF MEXICO TO ALASKA, FOLLOWED BY UPHEAVAL & BEGINNING OF ROCKY MTS.	RISE OF MAMMALS & BIRDS—DECLINE & EXTINCTION OF DINOSAURS. DEVELOPMENT OF MODERN FLOWERING PLANTS & DECIDUOUS TREES	YOUNGER SEDIMENTARY ROCKS LOCAL IGNEOUS ROCKS
			JURASSIC	APPALACHIAN MTS. BASE-LEVELED — PACIFIC COAST VULCANISM - SUBMERGENCE FROM COLO. TO ALASKA.	GIANT REPTILES (DINOSAURS) - FIRST BIRDS — PRIMITIVE MAMMALS — MANY INSECTS SIMILAR TO PRESENT FORMS	
			TRIASSIC	LARGE LAND AREA - ARIDITY CONTINUED — SOME ROCKS OF LAND-DEPOSITED ORIGIN - VULCANISM	REPTILES (CRAWLING, WALKING, FLYING, SWIMMING) DIVERSE & ABUNDANT. MANY COMPLEX MARINE ANIMALS — FORESTS MAINLY CONIFEROUS	
GENERAL EROSION INTERVAL						
PALEOZOIC ERA	ERA OF ANCIENT LIFE	DURATION VARIOUSLY ESTIMATED AT ABOUT 20 PER CENT OF ALL GEOLOGIC TIME	PERMIAN	GENERAL EMERGENCE - FOLDING OF APPALACHIAN MTS. — WIDESPREAD ARIDITY	DECLINE OF FERN TREES & RISE OF CONIFERS — GREAT VARIETY IN REPTILES & INSECTS — MANY MARINE INVERTEBRATES DISAPPEAR	OLDER AND MORE RESISTANT SEDIMENTARY ROCKS LOCAL INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS
			CARBONIFEROUS "THE COAL AGE": PENNSYLVANIAN	FLUCTUATING SEAS IN THE INTERIOR — FORMATION OF EXTENSIVE SWAMPS	VAST FORESTS OF FAST-GROWING TREES AND OTHER PLANTS. COMPLEX MARINE LIFE - RISE OF REPTILES AND INSECTS	
			CARBONIFEROUS "THE COAL AGE": MISSISSIPPIAN	WIDESPREAD SUBMERGENCE AND DEPOSITION OF SEDIMENTS	DEVELOPMENT OF SHARKS AND OTHER FISH — NUMEROUS AMPHIBIANS — ABUNDANT FORESTS OF FERNS & PRIMITIVE CONIFERS.	
			DEVONIAN	WIDESPREAD SUBMERGENCE - MOUNTAIN UPLIFT AND VULCANISM IN NEW ENG.	ABUNDANT FISHES WITH VERTEBRA AND PAIRED FINS. FIRST AMPHIBIANS, FIRST FORESTS (TREE FERNS)	
			SILURIAN	WIDESPREAD DEVELOPMENT OF PLAINS BY EROSION AND BY EMERGENCE	DEVELOPMENT OF FISHES — FIRST LAND ANIMALS (SPIDER-LIKE) — FIRST LAND PLANTS — ABUNDANT CORALS	
			ORDOVICIAN	SEDIMENTS DEPOSITED — MOUNTAIN BUILDING IN NEW ENGLAND AND CANADA	ABUNDANT MOLLUSKS AND TRILOBITES — EARLY FORMS OF FISH — NO EVIDENCE OF LAND ANIMALS OR PLANTS	
			CAMBRIAN	WIDESPREAD SUBMERGENCE AND DEPOSITION OF SEDIMENTARY ROCKS	FIRST ABUNDANT FOSSILS MAINLY OF SHELLED MARINE INVERTEBRATES (MOLLUSKS AND TRILOBITES)	
LONG INTERVAL OF UPLIFT AND EROSION						
PROTEROZOIC				MUCH MOUNTAIN BUILDING, METAMORPHISM OF ROCKS, AND VULCANISM	PRIMITIVE MARINE LIFE, MAINLY WITHOUT SHELLS, LEAVING ONLY MEAGRE FOSSIL REMAINS	ANCIENT CRYSTALLINE ROCKS
LONG INTERVAL OF UPLIFT AND EROSION						
ARCHEOZOIC				MOUNTAIN BUILDING AND VULCANISM. MANY EVENTS OBSCURED BY VAST LAPSE OF TIME	PRIMITIVE FORMS OF MARINE LIFE, PERHAPS ALGAE-LIKE. NO DIRECT FOSSIL EVIDENCE	
EARTH HISTORY EXTENDS BACK AND MERGES WITH EARTH ORIGIN						

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